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SHIPS

UPON NEW DESIGNS.

BY

CHARLES G. LUNDBORG.

BY ORDER OF THE HOUSE OF REPRESENTATIVES OF THE UNITED STATES OF AMERICA.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1884.

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48TH CONGRESS, 1st Session. } HOUSE OF REPRESENTATIVES. { MIS. DOC. No. 36.

IMPROVEMENTS IN STEAMSHIPS.

MEMORIAL

RELATING TO

INVENTIONS AND IMPROVEMENTS IN STEAMSHIPS BY CAPT. CHARLES G. LUNDBORG, FORMERLY OF THE ROYAL SWEDISH NAVY.

FEBRUARY 12, 1884.—Recommited to the Committee on American Ship-building and Ship-owning Interests and ordered to be printed.

To the Congress of the United States:

An effective navy and an adequate merchant marine are national necessities. The present condition of our Navy fills patriotic citizens with alarm and humiliation, while our merchant marine is inadequate to perform 15 per cent. of our ocean carrying trade. It is demonstrated by reliable statistics that the carrying capacity of our merchant marine has decreased in the last decade in about the same proportion that our exports and imports have increased. These startling facts have for some time challenged public attention, and they are now beginning to excite public concern.

While it is not our purpose in this memorial to discuss the causes of the present condition of our Navy and merchant marine, it may be proper, however, to revert briefly to a few facts in explanation of them. First, the diversion of the active capital of the country into enterprises of internal development; second, failure of the Government to encourage and promote, by wise and liberal legislation, the construction and navigation of an efficient and adequate merchant marine, able to compete successfully with foreign nations for the ocean carrying trade; third, the growth of a false economic doctrine, which holds that the carrying trade of the world belongs to the British because they are able to build and navigate steamships a trifle cheaper than the Americans.

The first of these causes operates to prevent the investment of American capital in shipping enterprises. The second tends to divert the energy and intelligence of American citizens from the ocean. The third encourages in our midst a powerful class who systematically antagonize every effort of enterprising citizens to remove the second cause, or to modify the consequences of the first; and the result is that we are practically without a Navy, and our foreign trade and commerce is carried in foreign bottoms. Unless we misinterpret the public opinion of this country, a crisis has been reached, and a change which will effect a remedy for this condition of things is now demanded. The only question is, What shall be the remedy? Before entering upon the solution of this question it may not be considered inappropriate here to refer to

the sound advice of some of the early statesmen of the Republic, whose views are pertinent to this subject.

Washington said in his second annual message:

> I recommend to your serious reflection how far and in what mode it may be expedient to guard against embarrassments from these contingencies [danger to our goods carried in foreign ships, by war] by such encouragement to our own navigation as will render our commerce and agriculture less dependent on foreign bottoms, which may fail us in the very moment most interesting to both of these great objects.

Madison said:

> If America should have vessels at all, she should have enough for all the purposes intended; to do all her own carrying, to form a school for seamen, laying the foundation of a navy, and to be able to support herself against the interference of foreigners.

Jefferson said:

> Our navigation involves still higher considerations. As a branch of industry, it is valuable; but as a resource of defense, essential. The carriage of our own commodities, if once established in another channel, cannot be resumed in the moment we desire. If we lose the seamen and artisans whom it now occupies, we lose the present means of marine defense, and time will be requisite to raise up others, when disgrace or losses shall bring home to our feelings the evils of having abandoned them.

Are the American people ready to heed the sound advice of these eminent statesmen and patriots? In the past, when the carrying trade of the world was performed in wooden ships, the United States held high rank among maritime nations; and the superior inventive talent, mechanical skill, and executive energy of her citizens enabled her to cope with the most powerful nations upon the high seas. It has always been a distinctive feature of American policy, both governmental and social, to encourage invention and promote innovation, and to this fact may be attributed all our triumphs upon land and sea.

From 1816 to 1840 the tonnage and value of our ocean traffic was greater in proportion to population than that of any other nation. During that period of our country's history we built faster ships and sailed them more skillfully than any other nation in the world. In the latter decades of the sailing era, nearly every important improvement in form, lines, structure, and equipment of vessels emanated from the brain of an American, and was utilized by an American shipbuilder.

When steam first came into use as a marine motor, Americans were the pioneers in its application and development. These are simple truisms of history, but they apply only to the era of wooden ships.

Up to 1860 the Americans had perfected the wooden ship. With boundless forests to supply material, with matchless genius to design, and with incomparable skill to construct, they led the world, and had not iron and steel so largely superseded wood in shipbuilding, the Americans would no doubt still hold the ascendency on the ocean.

The advent of the iron ship, however, radically altered the conditions and the abundant cheap supply of the material entering into its construction, together with the more general adoption of the steam-engine instead of sails, gave to England even greater advantages than had been previously enjoyed by the Americans in the era of the wooden ship. But while the materials of construction and the means of propulsion were undergoing these great changes, the essential conditions of shape and form of the hull remained practically the same. The sole endeavor of the English, in the prosecution of their supremacy upon the ocean, has been to build larger ships and to increase their speed, simply by the application of great engine power, without altering in any essential property their models. If we except the questionable improvement of greatly

increasing the proportion of length to breadth, the form of the ship of this period is essentially the same as it was fifty years ago, and, although great improvements have been made in almost every other branch of human pursuits, it would seem that the inventive genius of our age has here come to a stand-still. The invention of your memorialist, to which your attention is respectfully invited, is the first radical deviation, based upon scientific principles, from the prevailing ship model, and among the principles and advantages claimed for it we specify the following:

1st. The design makes it possible to combine the finest lines for high speed with great carrying capacity.

2d. The form of the aft part of the immersed hull with its submerged stern, which divides the water horizontally, permits, in the highest possible degree, great sharpness stern, or what is called "*a clean run*," which is the indispensable condition for high speed.

3d. The great width of the aft part of the ship's hull, which is a consequence of the submerged horizontal stern, affords ample room for the application of the greatest engine power compatible with the displacement.

4th. The design is eminently adapted for the use of twin screws, as the form of the submerged stern affords a perfect support to the propeller shafts. The great importance of this advantage will especially appear whenever it shall be desired to reach a very high speed, attainable only by a ship carrying engines of such great power that it cannot be economically used upon only one propeller of moderate size, or safely transmitted through one shaft, in which case it becomes necessary to divide the power upon two propellers and adopt twin screws. In a vessel of the ordinary type the propeller shaft must be hung up on brackets extending into the water, outside the ship for a considerable distance, and the difficulty of supporting and protecting shafts of very great weight in such an exposed position will be easily perceived; but this objection is entirely removed by the present design, which permits the propeller shafts to be carried all the way inside and supported firmly within the ship's hull.

5th. The propellers act constantly in solid water undisturbed by the proximity of the stern-post, rudder, and the overhanging part of the stern, as in ships of the usual model. This must cause an economy of power or a corresponding increase of speed.

6th. A vessel of this form will not roll or pitch as much as vessels of the common type, because the body of water over the projecting part of the hull will offer considerable resistance to such motion. Less pitching will also in a great measure tend to prevent "racing" by the propellers partly lifting out of the water; and this greater steadiness of the ship during its progress through the water must economize power or add to the speed.

7th. The rudder (or rudders, if two are used) may be made lighter, and have considerably less area than in ships of the ordinary kind, because the stern of the vessel, on account of its form, offers less resistance to lateral motion, thus requiring less power to swing or move it sideways. The resistance to the vessel's progress due to the rudder being proportionate to its surface, it follows also that the diminished area must lessen the resistance and tend to increase the speed.

8th. Owing to the increasing width of the hull below the load water-line, the ship will stand upright, and may be moved about or go to sea without ballast. Indeed, the more the vessel is lightened the greater becomes the stability, because the meta center rises with the greater beam much more rapidly than the center of gravity, and the same will

also, on account of the expanding side above water, take place if the ship should be loaded deeper than to the assumed load water-line. The great advantage of this property inherent to the design becomes evident from the known fact that most large ocean steamers must carry a considerable quantity of permanent ballast, the lost freight on which causes corresponding diminution of the earnings.

9th. The use of two propellers, having their shafts effectually supported and protected within the ship's hull, must add greatly to the security against accidents at sea, such as might disable a vessel with only one propeller, or where the propeller shafts, as usual with twin screws, run outside of the ship.

10th. The arched form of the hull, with the projecting sides below water, and the general absence of any plane surface exposed to the sea, admits of very great strength of construction, and with judicious application of water-tight compartments such a vessel may be made exceedingly strong, offering the best possible security against the violence of the sea and the perils of collision.

This invention is a bold step forward, but in strict conformity with and adherence to the scientific principles of naval architecture, and it is covered by letters patent in this country and in Europe. It has been examined by leading shipbuilders in this country, who approve and commend it, as appears from their testimonials hereto attached. May it not, therefore, be assumed that if this invention possesses the merit conceded for it by the eminent shipbuilders who have examined and approved it, that its development and application by the United States Government will be the surest and most speedy means of laying a reliable foundation for an effective navy, and for a merchant marine adequate to the demands of our ocean carrying trade in the transportation of American mails, passengers, and products, which are now carried in foreign bottoms, and for which the American people pay annually to foreign ship-owners over $140,000,000?

We respectfully submit this important invention to your most favorable consideration, for such action as may seem to be wise and expedient, in the hope that it may be the means of speedily restoring the United States to her former position of power and prestige upon the high seas.

Very respectfully,

CHARLES G. LUNDBORG,
Inventor and Naval Architect.

TESTIMONIALS OF PERSONS WHO HAVE EXAMINED THE INVENTION AND THE SCIENTIFIC PRINCIPLES UPON WHICH IT IS BASED.

WASHINGTON, D. C., *October* 24, 1882.

DEAR SIR: I beg to express my congratulations in relation to the probable establishment of a line of transatlantic steamers built on your designs.

Your letters from the most eminent shipbuilders and experts in our country tend to confirm me in my ideas formed last winter, when you kindly showed me your elements of design, model, and drawings, that vessels built in accordance therewith, furnished with the usual power for the displacement, will have great speed with increased carrying capacity, and great steadiness in heavy weather. Having made a study of strength in naval construction, I feel warranted in saying that with the same thickness of material, riveting, &c., your vessels will prove unusually strong.

Very respectfully, yours,

DANIEL AMMEN,
Rear-Admiral, United States Navy.

Capt. C. G. LUNDBORG,
Late of the Royal Swedish Navy.

W. H. WEBB, 64 CEDAR STREET,
New York, October 31, 1882.

DEAR SIR: Having examined the model presented by you this day, and which you have designed for the Atlantic merchant service, I find so much in accord with my own experience and practice of former years that I do not hesitate to give it my approval.

It possesses many important advantages over the generally accepted models of ocean steamers. Its general dimensions will secure very light draught, and with fine lines, as shown in the model, and adequate power, great speed can certainly be obtained.

Also, greater stability when light; less disposition to roll at sea when loaded; greater certainty of answering the helm quickly; large carrying capacity on a light draught; greater safety and comfort at sea.

It would be a satisfaction to me to see your views embodied in a large ocean steamer, and put in practical operation, that it might be shown and *proved* that the accepted models of the day are far from right and the best.

Yours, very respectfully,

W. H. WEBB.

Capt. C. G. LUNDBORG,
Naval Constructor.

MORGAN IRON WORKS, FOOT NINTH STREET, E. R.,
JOHN ROACH & SONS, PROPRIETORS,
New York, September 18, 1882.

DEAR SIRS: I have examined the model and specifications of Capt. C. G. Lundborg's plans for Atlantic express steamships, and I consider them just what is requisite for transatlantic steamers of greater speed, greater safety, and greater comfort to passengers than has hitherto been given to the traveling public.

Yours, respectfully,

EDWARD FARRON,
Engineer and Constructor to John Roach & Sons.

Messrs. CHAS. L. WRIGHT & CO.,
51 *Broadway*.

C. & R. POILLON, SHIPBUILDERS, &C., 224 SOUTH STREET,
New York, October 30, 1882.

GENTLEMEN: Having examined the drawings and calculations of Capt. C. G. Lundborg's model of steamship for the Atlantic service, we would state that we can see no objection to anything he claims, and in our judgment his model possesses several important advantages over the common form of steamships now in use, combining fine lines for speed, great stability, and light draught.

The advantage of two propellers, acting always in solid water, is very important to obtain a high rate of speed, also as a means of safety in case of accident to the machinery. The form of model gives great stability when light, avoiding the necessity of using ballast, thus saving cargo space, trouble, and expense.

In our judgment, Captain Lundborg's plans and specifications possess all the advantages claimed by him, as they contain all the elements of success for the Atlantic service, viz, speed, safety, comfort, large carrying capacity, and light draught.

Yours, truly,

C. & R. POILLON.

Messrs. CHAS. L. WRIGHT & CO.

ROOMS OF BOARD OF TRADE OF SAN FRANCISCO,
NO. 202 MARKET STREET,
San Francisco, September 20, 1882.

MY DEAR SIR: It is now over a year since I first examined your plans and specifications for steamships on your plan, and while at Washington, six months since, I also examined your model. Consequently I may consider myself fairly acquainted with your views in this connection, and I have no hesitation in asserting that in all essential points your model for ocean steamers possesses many important advantages. *Increased buoyancy*, or, otherwise expressed, *increased carrying capacity on a lighter draught*;

stability and steadiness in a seaway; greatly increased speed, and consequent economy in fuel —these very important points are justly claimed for your model, and these control the question of success in ocean steamships.

I trust that your valuable invention may be first introduced under American colors, and I have no doubt of its complete success if applied to properly constructed steamships.

With much respect, I beg to remain, sir, your obedient servant,

WILLIAM L. MERRY,
Vice-President San Francisco Board of Trade.

Capt. C. G. LUNDBORG, *Washington, D. C.*

THE WILLIAM CRAMP & SONS'
SHIPYARD AND MACHINE SHOP,
Philadelphia, October 20, 1882.

DEAR SIR: I have to apologize for not writing you sooner, but my time is so fully occupied in superintending the building and fitting out of the two steamships here, besides three others at Chester, at Messrs. Roach and Sons' yard—*that*, I hope, will partially plead my excuse.

About ten days ago I had finished extended and full investigation and calculations of your design. I do not think I left one point that I did not fully go into, and the result is that I fully indorse Captain Merry's and others' views of your plans and designs for an ocean steamship. I think it unnecessary to go into dry details or forward you my calculations, as you know, better than I can tell you, the results. I iooked for faults, and have failed to find them, and I now add my testimony for what it is worth as to the result of *actual investigation into the scientific pinniples involved in your designs.*

Again apologizing for the delay, I am, yours, truly,

J. M. LACHLAN.

Captain LUNDBORG.

NEW YORK, *October* 20, 1882.

MY DEAR SIRS: The design of an ocean steamship made by Capt. C. G. Lundborg, for the Atlantic Express Steamship Company of New York City, presents much that is novel, and after a thorough examination and analysis of its principal features, its fine lines, combined with great stability, and the capacity of the hull for the introduction of a much greater amount of propelling power than is now afloat, we unhesitatingly assert herewith that Captain Lundberg's ship must prove faster, and at the same time steadier and more profitable, than any other vessel of similar dimensions or capacity built on the prevailing type of model, and propelled by a single screw propeller wheel.

Both in the abstract and detail his plans are in the highest degree practical, when viewed in the light of the well-known principles of steam naval architecture.

It is beyond dispute that the maximum efficiency of the single-screw propelling wheel has been already reached in sea-going steamers. More propelling power, and its consequent speed, can be achieved only by the use of twin screws, and this feature in Captain Lundborg's plan makes its superiority obvious to us.

We remain, respectfully, yours,

NATHANIEL MCKAY,
CORNELIUS W. MCKAY,
Naval Architects.

Messrs. CHARLES L. WRIGHT & CO., *New York.*

[Opinion of the London Engineer of June 24, 1881.]

LUNDBORG'S HIGH SPEED STEAMSHIPS.

The proposals which have recently been put forward for the construction of a fleet of high-speed Atlantic steamers, the launch of the City of Rome, the building of gigantic ships by the Guion and Cunard Companies, all point the same way, and indicate the existence of a desire to place England and America virtually yet closer together than they are now. In certain respects the problem to be solved is very simple. Most of the conditions to be fulfilled are perfectly understood. An average speed of at least twenty miles an hour must be maintained incessantly while a storm-swept ocean, 3,000 miles broad, is being traversed. It is known that there is no pos-

sibility of doing this with vessels of less than 5,000 tons displacement, and it is nearly certain that much more will be required. An average speed of 20 miles means that a higher velocity than this must be attained now and then when wind and sea are not dead against the ship. Thus it comes to pass that the express Atlantic steamer of the future must be a vessel of enormous engine power. We have already pointed out the great difficulties that stand in the way of utilizing 14,000 or 15,000 indicated horse-power at sea. It will be readily conceded that although the conditions of success are, as we have said, known, the means of securing these conditions have not been settled. It is evident, however, that it is of the utmost importance that the resistance of the ship should be as small as possible. Now, the late Mr. Froude taught the world a lesson which has often been misunderstood. He pointed out that the form of a ship's hull had little or no effect on the power required to propel her, and in saying that he was quite right in one sense, but he did not stop there. He added that eddy making was the great source of resistance, and eddy making depends very much indeed on the shape of a hull. To eddies and skin friction the whole, or very nearly the whole, resistance of a ship may be attributed, but these are both largely dependent on the shape of a ship's hull. Now, it is not perhaps too much to say that no further progress is possible in the direction of reducing the resistance of ships so long as we adhere to existing models. The London and Northwestern Railway Company's Holyhead steamer Violet is probably at this moment the fastest steamship in the world. She has attained a velocity not much less than that of torpedo boats, but no express Atlantic steamer could be built like her. The Violet is a paddle boat, and what will suit paddles will not answer for screws. A new departure is necessary.

We illustrate at page 461 a design prepared by Capt. C. G. Lundborg, of Sweden, a naval architect, and we give prominence to this design, because it appears to us to be full of promise. It has been argued that the design is not a good one for a cargo steamer, and we concede at once that it is not worth while to build a steamer of this type to attain a speed of eight or nine knots. Our readers, we must ask to bear in mind, have before them a design for an Atlantic passenger steamer, which, while affording ample space for passengers and valuable cargo, has been prepared with the primary object of attaining a velocity of twenty to twenty-one knots an hour, with a comparatively moderate expenditure of power. Our engravings show the form of the ship so fully that little or no description of any kind is necessary. It will be seen that the prominent idea involved is that of making the main body of the ship divide the water horizontally instead of vertically. It will perhaps be conceded without much hesitation that by adopting this system of construction it becomes possible to build a ship of the greatest capacity for a given draught—an advantage which speaks for itself. But besides this it is also evident that this ship of shallow draught and great capacity can have admirable lines. In other words, her resistance may be reduced to a minimum. The principle admits of the naval architect imparting to his ship a splendid clean run aft, and the screws can be carried far astern and yet be perfectly supported. The advantages to be derived from thus placing the screws far astern have been insisted on by the late Mr. Froude. It will also be seen that no scheme has ever before been put forward which is so perfectly adapted to the use of twin screws.

* * * * * * *

The great height of the metacenter above the center of gravity of the ship would safely permit yet another deck to be added, even with the unusual height of more than 9 feet between the decks, thus largely increasing the space and giving room for a much greater number of passengers.

The projection of the hull below water will go far to secure immunity from rolling, and presents no difficulties of construction which cannot easily be overcome, while it will tend to give a strong ship as well as one which will be fast.

In conclusion, we may point out that we have in Captain Lundborg's design one which gives a ship with exceedingly fine lines and the smallest possible amount of what has been termed by Rankine "augmented surface," whenever the size of the ship is such that the draught can be about half the beam. Captain Lundborg's patents have only been completed within the last two months, but his designs have been very favorably received by several eminent authorities, both in this country and the United States. Captain Lundborg's designs are not only the result of mathematical investigation, but of long and skillfully-conducted experiments, which gave, without any exception, results always in favor of Captain Lundborg's model. We trust that the merits of the design will soon be brought to a practical test by the construction of a steamer of moderate size. It is impossible to overrate the importance of the problem which we dare to think Captain Lundborg has gone some way toward solving.

REMARKS EXPLANATORY OF THE INVENTION.

(With drawings.)

In presenting this subject, which is so purely technical in its character, I realize the difficulty in making myself fully understood. I will endeavor, however, to explain as clearly as possible the origin, development, and principles of my invention for ocean steamships and other vessels, set forth very briefly in the memorial before your honorable committee.

During many years of active life at sea I had abundant opportunity to observe many curious facts and phenomena relating to the motion of vessels, the nature of which could not be explained satisfactorily upon the generally accepted knowledge and theories of the laws of resistance governing bodies borne upon and moving through the water. By constant observation of these phenomena I was soon impressed with the belief that our knowledge of the laws of resistance was quite superficial, if not entirely erroneous; and, therefore, I at once entered upon this field of investigation, to which I devoted myself almost exclusively, availing myself of the works of the ablest men before me, who had treated upon this subject.

I was not unacquainted with the previous labors of several of my countrymen, such as the celebrated Chapman, who justly holds, in scientific naval architecture, a rank equal to that of Newton in astronomy, and after him Lagerhjelm and Forselles. Nor was I altogether unfamiliar with the researches of Euler, D'Alembert, Condorcet, and De Borda, the names of whom will illumine the pages of science for all time. But these great men, excepting Chapman and, to some extent, Euler, did not especially direct their genius toward practical improvements in shipbuilding, and I could, therefore, not avoid thinking that very much yet remained to be learned, and that great improvements in naval architecture, if approached under the guidance of some scientific knowledge, could and ought to be made. This was many years ago, before the investigations of Rankine and Froude. But what was true then is true now, although perhaps in a modified degree. It cannot possibly be otherwise, for surely we are, with the style of ship to-day traversing the ocean, just about as far from perfection as we were fifty years ago with the mail coach when compared with the palace car of to-day. My first step in the pathway thus indicated was naturally in the way of experiments, which might perhaps seem presumptuous and unnecessary in view of the great achievements of my illustrious predecessors. But a natural taste for this kind of scientific research prompted me to pursue the investigation. Mr. Froude was then unknown to the world, as this was before he became famous through his towing experiments with the Greyhound and his investigations of "friction resistance," together with the scientific deductions derived therefrom. Nor had I before this any opportunity to become acquainted with Colonel Beaufoy's experiments, which I much regret, because some knowledge of them would probably

have given me great assistance and saved much valuable time by pointing out, almost at the outset, the right direction for my labor.

The object of my first experiments was to ascertain whether there was any difference in the resistance to a body floating at the surface of the water and one wholly submerged. I had reason to believe there was a difference, as that would help to explain many phenomena otherwise inexplicable, and I very soon came to a certainty upon that point beyond any possibility of a doubt, as proved by numerous experiments.

An example of these experiments and a short description of the manner in which they were conducted will give a general idea of the method pursued.

The experiments were made in a tank 200 feet long, 6 feet wide, and 3 feet deep, built of plank, and nearly filled with water. In this tank the bodies were towed at various speeds, floating or submerged to different depths. About 6 inches above the surface of the water, over the middle of the tank, there was a small carriage-way with rails 4 inches apart for a little wagon to travel upon. The frame of the wagon was rectangular, 2.5 feet long, and on the inside of its two longitudinal sides, parallel to the track, there was another smaller truck, which had room to move only a few inches. On the hind axle of this inner truck was fixed a vertical steel bar, one inch wide, thin and sharp at both edges like the blade of a knife, reaching down into a loop attached to the bow of the body to be tried. This vertical bar was adjustable, sliding up and down in a groove on the axle, and thus allowed to reach the loop aforesaid without touching the water when the body floated on the surface, but reaching down into the water sufficiently deep to take hold of the body when the latter was submerged. A dynamometer of simple construction, indicating accurately the pressure to within the one hundredth part of a pound, was fixed on the frame in front of the inner small truck, to which it could be connected, so that a force tending to drag this truck, with its descending bar, away from the dynamometer was shown by the latter and registered by a pencil attached to the index on a strip of paper drawn across between two small rollers, acted upon and set in motion by means of a string around a small pulley on the axle. Any variation in the pressure on the dynamometer would thus show itself by a wave-line on the slip of paper, while, when the pressure was constant, the line would be straight. The body in the water, held by the descending bar, caused by its resistance the inner truck to recede as much as permitted by the tension of the spring, the amount of resistance being indicated by the dynamometer, as before mentioned.

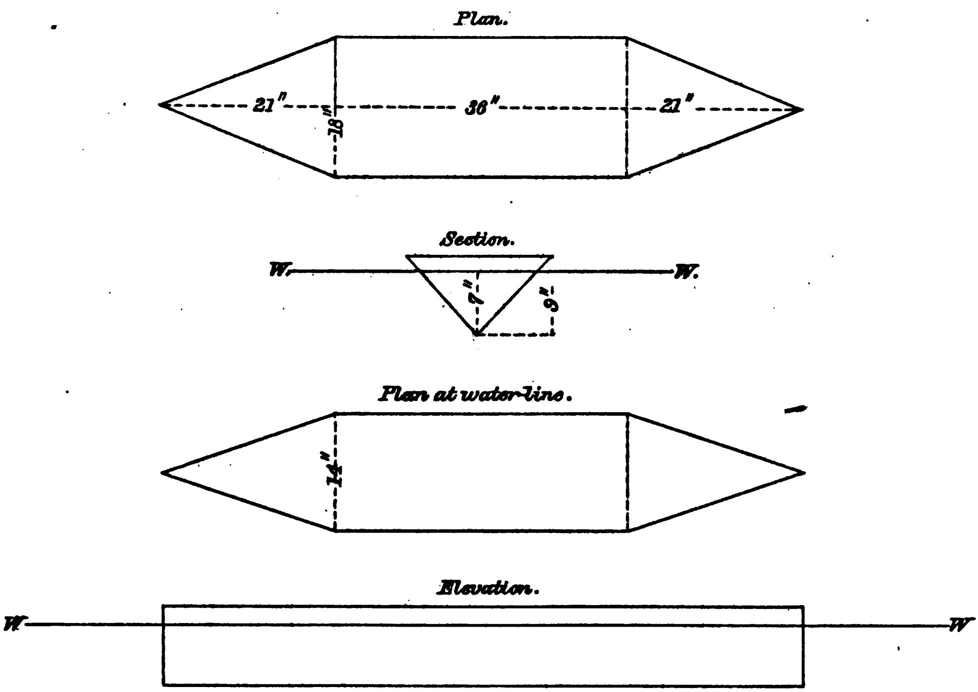
It will be seen that in this way no correction was needed for the power required to move the larger truck on the rails, as the resistance to the body in the water, due to its velocity, was obtained independently of the force needed to move the carriage on the rails, the velocity of which was, of course, the same as that of the body towed through the water.

The motion was obtained by a small water-wheel, acted upon by a jet of water from a pipe descending from a tank placed above, nearly filled with water, the level of which was maintained at the same height by an inflow of water, and the flow through the descending pipe to the wheel was thus subject to an unvarying pressure.

The flow of the water being regulated by a cock, it was easy to impart a uniform motion to the wheel and to its axle, to which cylinders of various diameters were attached, according to the speed desired, around which a fine cord of silk connected with the frame carriage on the rails, before described.

A few preliminary trials with the body attached to the descending bar, but not to the dynamometer, showed the flow of water necessary to produce the desired speed, and when the velocity was found to be uniform the dynamometer was attached and the resistance noted. In order to avoid any sudden jerk in the beginning of the experiment the water was let on gradually, until the required flow and a uniform speed was reached, which occurred generally within 20 or 30 feet from the start. In this way usually ten and sometimes twenty runs were made with the same velocity, and a mean taken of the result.

The resistance thus obtained by each run, varied generally very little, the difference seldom amounting to more than 1 or 2 per cent. of the whole resistance.



In the experiment referred to as an example there were two bodies used, of equal form and dimensions, made of white pine and painted. As will be seen by the sketch, the length of the bodies was 78 inches= 6.5 feet; greatest breadth 18, and depth 9 inches. The section was that of a right angled triangle. When put into the water the draft was 7 inches, thus giving 2 inches of "freeboard"; the greatest breadth in the water-line=14 inches; area of the water-plane, 798 square inches (=5.542 square feet); displacement, 2793 cubic inches and immersed surface=1379.1 square inches=9.576 square feet.

The experiments gave the following mean resistance at velocities of 1, 2, 3, 4, and 5 feet per second, respectively:

	Pounds.
At 1 foot per second	0.1274
At 2 feet per second	0.5247
At 3 feet per second	1.2116
At 4 feet per second	2.2096
At 5 feet per second	3.5401

The other body being adjusted to the same draft, and experiments with it made in similar manner, gave the following results:

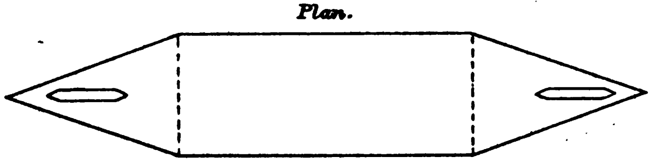
Resistance:	Pounds.
At 1 foot velocity	0.1302
At 2 feet velocity	0.5380
At 3 feet velocity	1.2245
At 4 feet velocity	2.2286
At 5 feet velocity	3.5657

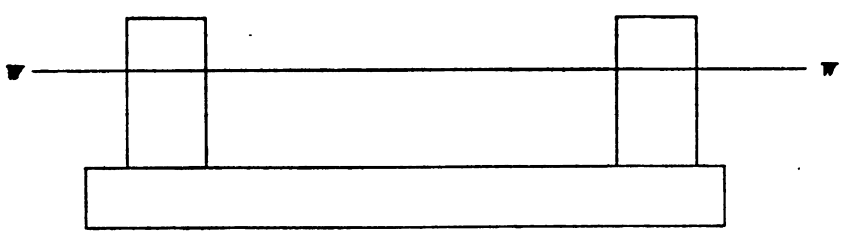
It will be seen that the latter body had a slightly larger resistance than the first one, owing, probably, to some inappreciable inequality in form or size; but the difference is very small, the mean being—

Resistance:	Pounds.
For 1 foot velocity	0.1288
For 2 feet velocity	0.5313
For 3 feet velocity	1.2180
For 4 feet velocity	2.2191
For 5 feet velocity	3.5529

Both bodies were then cut down to the water line, or, in other words, all the wood forming the "freeboard" was planed away. At each end of this new upper surface there were fixed, as shown in accompanying sketch, an upright board, 10 inches wide and 1 inch thick, sharpened at the edges so as to cut easily through the water. The body was weighted down by lead in its lower part, so as to have its upper surface just even with the water, in which state the displacement and immersed surface was exactly the same as in the former experiment.

Plan.





Elevation.

More weight being now added, the body sunk below the surfce, supported only by the buoyancy of the two upright boards; and by the means of small pieces of lead, placed on the top of the boards, the body was submerged with its upper surface one foot below the water and adjusted in a perfectly horizontal position. In this state there was no considerable alteration in the displacement, only by the additional cubic contents of the immersed part of the boards; but the immersed or wetted surface was greatly increased by the additional upper surface of

the body, and also by the surface of the upright boards. The immersed surface was then:

	Square inches.
Surface as before	1379.1
Upper surface	796.0
Surface of the two boards	481.9
Total immersed surface	2659.0

Equal to 18.465 square feet.

The immersed surface being thus increased 1279.9 square inches, or 8.888 square feet, it follows that the resistance should be increased by the friction owing to that increase of surface and by the slight additional direct resistance due to the boards.

Assuming, then, the friction for 1 square foot of surface, at the velocity of 1 foot per second, to be 0.0038 pounds, in accordance with experiments of the late Mr. Froude, and adhering to the usual expression that it varies as the square of the velocity, we have:

	Pounds.
Friction on 8.888 square feet, at 1 foot velocity per second	0.0338
Friction on 8.888 square feet, at 2 feet velocity per second	0.1351
Friction on 8.888 square feet, at 3 feet velocity per second	0.3040
Friction on 8.888 square feet, at 4 feet velocity per second	0.5404
Friction on 8.888 square feet, at 5 feet velocity per second	0.8444

The resistance of the two upright boards was obtained by a separate set of experiments, and ascertained to be:

	Pounds.
For each board at 1 foot velocity per second	0.0183
For each board at 2 feet velocity per second	0.0738
For each board at 3 feet velocity per second	0.1691
For each board at 4 feet velocity per second	0.3049
For each board at 5 feet velocity per second	0.4844

But from this the friction should be deducted, as it is included in that for the 8.888 square feet above, namely:

	Pounds.
Friction on 240.95 square inches = 1.673 square feet, at 1 foot velocity	0.0063
Friction on 240.95 square inches = 1.673 square feet, at 2 feet velocity	0.0252
Friction on 240.95 square inches = 1.673 square feet, at 3 feet velocity	0.0567
Friction on 240.95 square inches = 1.673 square feet, at 4 feet velocity	0.1008
Friction on 240.95 square inches = 1.673 square feet, at 5 feet velocity	0.1575

Which leaves the resistance (less friction) for each board:

	Pounds.
At 1 foot velocity	0.0120
At 2 feet velocity	0.0486
At 3 feet velocity	0.1124
At 4 feet velocity	0.2041
At 5 feet velocity	0.3269

The resistance of the submerged body should, therefore, be as follows:

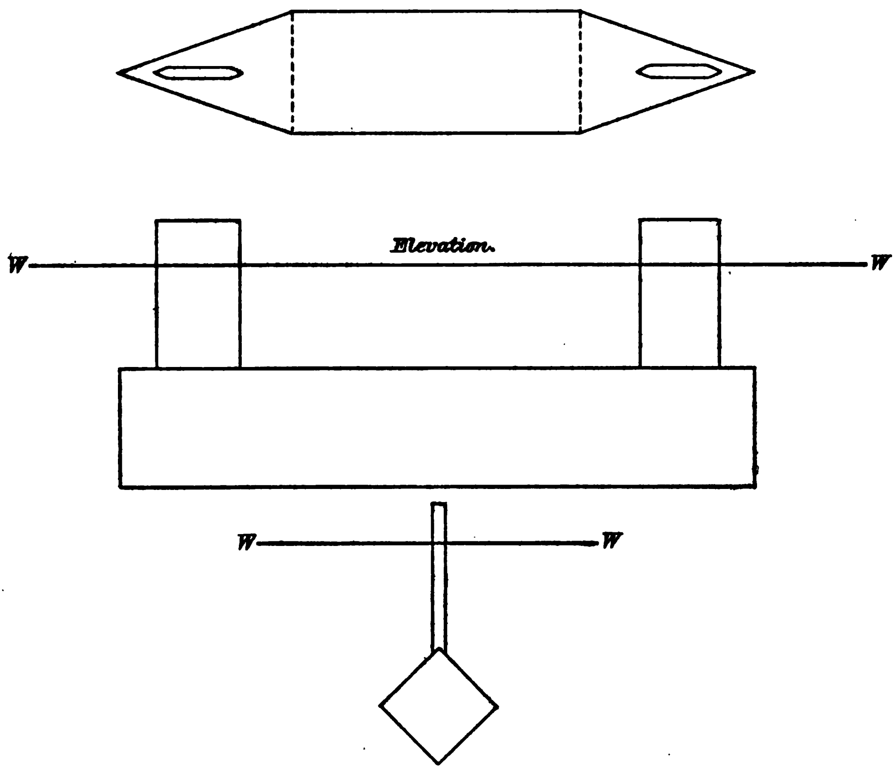
	Speed in feet per second.				
	1.	2.	3.	4.	5.
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Resistance as in first experiment	0.1288	0.5313	1.2180	2.2191	3.5529
Friction on additional 8.888 square feet	0.0338	0.1351	0.3040	0.5404	0.8444
Resistance of the two boards (less friction)	0.0240	0.0972	0.2248	0.4082	0.6538
Total calculated resistance	0.1866	0.7636	1.7468	3.1677	5.0511

The experiment, however, proved the actual resistance to be:

	Pounds.
For 1 foot velocity per second	0.1801
For 2 feet velocity per second	0.7182
For 3 feet velocity per second	1.6094
For 4 feet velocity per second	2.8470
For 5 feet velocity per second	4.4211

The two bodies were then joined together along their upper surface, thus making one body together, the section of which formed a square, as shown in the sketch, and the float-boards were fixed in the upper

Plan.



Section.

angle of the body. The displacement, as well as the immersed surface, was in this case exactly twice that of the body in the first experiment, the displacement being = 5586 cubic inches and the surface = 2758 square inches = 19.152 square feet. It follows, then, that if the resistance of this double body did not change by its being submerged, its resistance should be twice that of the body in the first experiment, plus the resistance of the two boards:

	Speed in feet per second.				
	1.	2.	3.	4.	5.
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Resistance by first experiment (twice)	0. 2576	1. 0626	2. 4360	4. 4382	7. 1058
Resistance of the two boards	0. 0366	0. 1472	0. 3382	0. 6098	0. 9688
Total calculated resistance	0. 2942	1. 2098	2. 7742	5. 0480	8. 0746

But the actual resistance, as found by the experiment, was:

At 1 foot velocity per second	0.2872
At 2 feet velocity per second	1.1465
At 3 feet velocity per second	2.5680
At 4 feet velocity per second	4.5409
At 5 feet velocity per second	7.0512

The result of these three experiments may, accordingly, be presented thus:

	Speed in feet per second.				
	1.	2.	3.	4.	5.
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Mean resistance of the bodies at the surface	0.1302	0.5380	1.2245	2.2286	8.5657
Calculated resistance of the body submerged 1 foot below the surface	0.1866	0.7636	1.7468	3.1677	5.0511
Actual resistance by the experiment	0.1801	0.7182	1.6004	2.8470	4.4211
Difference	0.0065	0.0454	0.1374	0.3207	0.6300
Calculated resistance of the two bodes joined together, at 1 foot below the surface	0.2942	1 2698	2.7742	5.0480	8.0746
Actual resistance, by the experiment	0.2872	1.1465	2.5680	4.5409	7.0512
Difference	0.0070	0.0633	0.2062	0.5071	1.0234

It will be seen that the difference in resistance below and at the surface amounted to over 12 per cent. when the velocity was 5 feet per second.

It should, however, be observed that, in calculating the friction as above, it is assumed to vary as the square of the velocity; but this ratio is too high, as proved by the experiments of the late Mr. Froude and others, the index of power expressing the law of friction for a surface of that kind and length being 1.856. With this correction, we shall have:

	Speed in feet per second.				
	1.	2.	3.	4.	5.
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Resistance of the body at the surface, by experiment as before	0.1288	0.5313	1.2180	2.2191	3.5529
Friction on 8.888 square feet according to the index of power 1.856	0.0338	0.1224	0.2063	0.4429	0.6702
Resistance of the two boards, less friction, at the above index	0.0240	0.1020	0.2772	0.4448	0.7190
Calculated total resistance below the surface	0.1866	0.7537	1.7015	3.1068	4.9421
Actual resistance	0.1801	0.7182	1.6094	2.8470	4.4211
Difference	0.0065	0.0355	0.0921	0.2598	0.5210

The calculated resistance thus corrected, at 5 feet velocity per second, being 4.9421, while the actual resistance was only 4.4211, shows yet a difference of over 10 per cent. in favor of the submerged body.

The position of the float boards was then changed to one of the side angles, thus altering the position of the body so that the wedges in both ends became horizontal instead of vertical. The experiment gave then the following result:

Resistance at 1 foot velocity per second	0.2859
Resistance at 2 feet velocity per second	1.1394
Resistance at 3 feet velocity per second	2.5472
Resistance at 4 feet velocity per second	4.4665
Resistance at 5 feet velocity per second	6.9353

The resistance in this case was, as will be observed, less than in the former experiment when the wedges at the ends were vertical. The bodies being both submerged, there is no apparent reason for this remarkable difference, but the fact was proved by many subsequent experiments with bodies of different form and size. There was in this respect but little difference in the resistance, whether the wedge in the forward end of the body was vertical or horizontal, the angle of incidence being equal; but the resistance was always considerably diminished whenever the stern wedge was in a horizontal position. With two bodies of the same displacement and surface, and alike in every respect, except that the stern wedge in one was vertical while horizontal in the other, the difference in the resistance at a speed of 6 feet per second varied from 2 to 5 per cent. in favor of a flat stern.

Having thus shown the manner in which these experiments were conducted, I will not consume more time by citing further examples. A great number of experiments were made with bodies varying greatly in form as well as in size, and they gave, without exception, results from which no other conclusion could be drawn, than that the resistance of the water is considerably greater at the surface than deeper down.

Inspection of the example given will also show that the resistance at the surface increases at a higher ratio than as the square of the velocity, and also that the ratio increases with the speed. Thus it will be seen that the index of power expressing the law of resistance for the body at the surface, was:

For a velocity between 1 and 2 feet per second	2.0444
For a velocity between 2 and 3 feet per second	2.0450
For a velocity between 3 and 4 feet per second	2.0852
For a velocity between 4 and 5 feet per second	2.1093

But the resistance of the body submerged below the surface increases at a lower ratio than the square of the velocity, the index of power being for the submerged double body:

For velocity between 1 and 2 feet per second	1.9970
For velocity between 2 and 3 feet per second	1.9909
For velocity between 3 and 4 feet per second	1.9813
For velocity between 4 and 5 feet per second	1.9722

It is not my purpose to attempt an investigation as to whether the facts here set forth may be satisfactorily explained by the wave theory or any other hypothesis. The important truth once established, that the resistance is greater at the surface than below it, the question naturally arose how to utilize and take advantage of such knowledge.

The resistance being greatest at the surface, or in the load water-line, where the body of water is ruptured by the cut-water and bow of the ship, clearly suggested the idea that the ship ought to be designed so as to diminish that resistance as much as possible, and this could only be done in one way, namely, by increasing the sharpness, or diminishing the angle of incidence at that point.

But the practical application of this principle met, at the outset, with formidable obstacles. The ordinary type of vessel presents in every case the most obtuse angle of incidence, or the "bluffest" part of its bow, just at the surface of the water, where the resistance is greatest, while the sharpness, and the consequent facility for dividing the fluid, increases with the depth below the surface, where the resistance is the least. Increased sharpness at the load water-line, implied with the common type of ship, necessarily diminished displacement, and it soon became evident that a solution of the problem, how to conciliate the indispensable qualities of a sea-going ship, such as buoyancy, stability, obe-

dience to the helm, carrying capacity and easy behavior in a sea way, with a greatly diminished angle of obliquity at the surface of the water, demanded an entirely novel form of the hull, and a design altogether different from the common notions of shipbuilding. Great sharpness at the water-line without diminished displacement could only be possible by increasing the volume of the lower part of the hull in order to allow a narrow water-line, permitting a sharp entrance and run at the surface.

The primary object being to design a vessel of very high speed, greater than could be obtained by the ordinary style of ship, naturally suggested the use of twin screws, as the division of power upon two propellers instead of one, would make it possible to apply a far greater aggregate propelling power, than could be economically used and transmitted through one propeller shaft.

The obstacles in the way of attaining a speed of 20 knots by a sea-going ship of the ordinary type, with only one propeller, are so great as to make it virtually impracticable. The greatest power hitherto transmitted through one shaft is about 12000 indicated horse-power, but a much greater power would be needed for the ocean steamer designed to reach a speed of 20 knots. The frequent breaking of the propeller shafts of large steamers with powerful engines tends to prove that the limit of safety for the single propeller shaft has been reached; and hence the absolute necessity of two propellers, each taking up one-half of the great power required for high speeds, becomes more and more evident. The marine engine of the present day, immensely improved as it has been during the last decade, is yet of so great weight in comparison with the power developed, that a vessel must be of large size to carry the heavy load of machinery necessary to propel it at a high rate of speed. It is clear that, if it should be made practicable to use the locomotive type of boiler in ocean steamers, as well as in steam-launches and torpedo-boats, the weight of machinery would be greatly reduced. But even if such a desirable improvement should occur, it would not affect the size and weight of the propeller shaft, through which the power from the engine must be transmitted, and therefore cause no modification of the necessity for twin screws in ships designed for high speed.

A serious drawback against the application of twin screws, with great power, to ships of ordinary form exists, however, in the fact that the shafts must, for a long distance, be supported on struts in the water outside the ship; objection of little weight when the shafts are slender and light, but of great importance when they must be large and heavy, say 24 inches in diameter. In that case, the length of the shaft thus hung up outside would be, in a large ship with fine run, about 75 feet, and its weight would reach some 40 or 50 tons; and the practical difficulty in the way of firmly supporting such a heavy load in this exposed position will readily be understood.

During the progress of the investigations which finally led to the design now presented, it soon became evident that the adoption of the principle of having the greatest sharpness of the ship at the surface of the water, as a basis for the design, favored in an eminent degree the use of two propellers, the shafts of which could be firmly supported within the ship's hull, thus avoiding the use of struts and brackets in the water outside.

The solution of the problem, how to design a vessel capable of the highest speed and possessing at the same time, in an eminent degree, all the good qualities of a safe and comfortable ocean ship (sea-boat), brought also along with it, as a necessary corrolarium, the union of very

fine lines, suitable for great speed, with large carrying capacity, on a moderate draught of water.

During the many years that these researches have lasted there were, as may be imagined, many successive steps, and a great number of designs made before the present one was reached. A great number of models, according to their different designs, were made and experiments with them had, in comparison with others of the ordinary type. These experiments were made in the tank and with the apparatus already described, the results of which proved that the design was founded upon correct principles. A model according to the present design, considerably larger than these now presented, was also tried, the resistance curve of which is shown herewith. The experiments were conducted in conformity with the system of the late Mr. Froude, and a brief explanation of that system may, therefore, not be inappropriate.

Mr. Froude, who during many years conducted experiments for the British Admiralty, and to whom naval architecture, as a science, owes the greatest debt, was the first who showed how experiments with a small model in a tank could be made to give data from which reliable conclusions might be drawn as to the actual performance of the ship itself. The model being an exact fac-simile of the ship's hull and made according to an accurate design of the vessel, is in the experiment drawn through the water in the tank at various speeds and the resistance of the water noted, and also any phenomena that may become apparent during the progress of the model through the water, such as creating waves, rising or dipping of the bow or stern, &c., all of which indicate what will actually take place with the ship itself at a *corresponding* speed in smooth water.

It is clear that during the experiment the model cannot be tried at the actual speed of the ship, but at what is called *corresponding speeds*, which means that the actual speed of the ship in knots per hour has its comparative speed for the model in feet per minute.

These corresponding speeds are calculated according to the analogy

$$L : l = V^2 : v^2,$$

in which L is the length of the ship, l the length of the model, V the speed of the ship, and v the corresponding speed of the model, both in feet per minute. The analogy expressed in words will be: The length of the ship is to the length of the model as the square of their respective speeds; or the speed of the ship is to the speed of the model as the square root of their respective lengths.

From the above analogy we obtain the equations:

$$\frac{L}{l} = \frac{V^2}{v^2} \text{ and } L\,v^2 = l\,V^2,$$

whence:

$$v^2 = V^2\frac{l}{L} \text{ and } v = V\sqrt{\frac{l}{L}}.$$

From this last equation the corresponding speeds of the model are obtained. If, for an example, the length of the ship is 360 feet, the length of the model 10 feet, and the speed of the ship 12 knots ($=12 \times 101.33 = 1216$ feet per minute) the corresponding speed will be:

$$1216\sqrt{\frac{10}{360}} = 1216\sqrt{\frac{1}{36}} = \frac{1216}{6} = 202.67 \text{ feet.}$$

The resistance of the model at any speed being ascertained by the experiment, the actual resistance of the ship at the corresponding speed is found by the following rule: Multiply the cube of the quotient, obtained by dividing the length of the ship by the length of the model, by the resistance of the latter in pounds, and the product is the resistance of the ship in pounds. Or, in algebraic language, calling the respective lengths of the ship and model L and l as before, the resistance of the model r and the resistance of the ship R,

$$R = r\left(\frac{L}{l}\right)^3.$$

These two equations: $\frac{L}{l} = \frac{V^2}{v^2}$ and $R = r\left(\frac{L}{l}\right)^3$, express Mr. Froude's law for model experiments.

The effective horse-power required to propel the ship at any speed is easily found by multiplying the resistance of the ship by the speed in feet per minute and dividing the product by 33000; or by the equation

$$\text{E. H. P.} = \frac{RV}{33000}.$$

Model experiments conducted according to Mr. Froude's system consist therefore in ascertaining by experiments in a tank the resistance of a model of the ship at "corresponding speeds," and calculating the resistance and effective horse-power required to propel the vessel at various speeds according to the above equations.

It will be observed that in conducting such experiments the speed of the model should be regulated so as to perform the precise number of feet per minute at a perfectly uniform rate, according to the calculated corresponding speed table. With delicate and well-adapted machinery this can easily be accurately done; but with less perfect arrangements it may sometimes happen that the model will be found to have a uniform rate of speed although the number of feet run per minute may not be exactly as required to correspond to the precise number of knots for the ship. It is clear, however, that there is no absolute necessity for being confined to the precise number of feet per minute, as equally reliable results will be obtained by observing the resistance of the model at any uniform speed in the vicinity of the desired velocity. The difference in that case would only be, that the result obtained from the experiment, or the accordingly calculated resistance and effective horsepower would be that for the ship going at a speed to which the actual number of feet made by the model during the experiment, would be the corresponding speed. The speed of the ship corresponding to that of the model will easily be found from the equation

$$\frac{L}{l} = \frac{V^2}{v^2},$$

whence:

$$V^2 = v^2\frac{L}{l} \quad \text{and} \quad V = v\sqrt{\frac{L}{l}}.$$

By examining the above equations it will be seen Mr. Froude's system for tank experiments with models is in accordance with the assumption proved by experience to be nearly correct within moderate speeds for vessels of the ordinary type, namely, that the resistance of the water

increases as the square of the velocity; and that for two vessels of the same form, but different displacement, the resistance per square foot of immersed or "wetted" surface for equal speeds is equal, and that therefore at equal speed the total resistance is proportionate directly to the immersed surface. In order to show this more clearly, let

L represent the length of the ship as before.
l, the length of the model.
A, the immersed area of the ship.
a, the immersed area of the model.
V, the speed of the ship.
v, the speed of the model.
r, the resistance of the model at v speed.
r^1, the resistance of the model at V speed.
R, the resistance of the ship at V speed.

Then the resistance per square foot of the immersed surface of the model at v speed $=\frac{r}{a}$, and at V speed $=\frac{r^1}{a}$. According to the accepted law of the resistance being proportionate to the square of the velocity, we have then:

$$r : r^1 = v^2 : V^2, \text{ and } r^1 = \frac{r\,V^2}{v^2}.$$

The resistance per square foot of the model at V speed is therefore $=\frac{r\,V^2}{a\,v^2}$; and as the resistance of the ship and model at equal speeds are to each other in the same proportion as their immersed surfaces, it follows that

$$r^1 : R = a : A,$$

whence:

$$r^1 = \frac{a\,R}{A}.$$

From the two values of r^1 we have, then,

$$\frac{r\,V^2}{v^2} = \frac{a\,R}{A}; \qquad \frac{A\,r\,V^2}{v^2} = a\,R;$$

and

$$R = \frac{A r\,V^2}{a\,v^2} = \frac{A}{a} \cdot \frac{r\,V^2}{v^2}.$$

But similar surfaces are to each other as the square of their respective dimensions, and, consequently

$$A : a = L^2 : l^2,$$

or,

$$\frac{A}{a} = \frac{L^2}{l^2};$$

and substituting this value of $\frac{A}{a}$ in the foregoing equation, we have:

$$R = \frac{L^2}{l^2} \cdot \frac{rV^2}{v^2}.$$

If, now, the size of the model were such that the proportion of its dimensions to those of the ship were as $v^2 : V^2$, or $l : L = v^2 : V^2$, whence $\frac{L}{l} = \frac{V^2}{v^2}$, and substituting $\frac{L}{l}$ for $\frac{V^2}{v^2}$ in the above equation, we obtain:

$$R = \frac{L^2}{l^2} \cdot \frac{rL}{l},$$

and

$$R = r \cdot \frac{L^3}{l^3} = r\left(\frac{L}{l}\right)^3,$$

as in Mr. Froude's law.

Pursuing the subject further, in order to find the relation that the resistance and velocity of the model and ship bear to their respective displacements, according to Froude's law, and calling the displacement of the model d, and that of the ship D, and noting the equations:

$$R = r\left(\frac{L}{l}\right)^3 \text{ and } \frac{L}{l} = \frac{V^2}{v^2},$$

we know that the displacements are to each other as the cube of the dimensions, or

$$d : D = l^3 : L^3,$$

whence

$$\frac{D}{d} = \frac{L^3}{l^3} = \left(\frac{L}{l}\right)^3,$$

and substituting $\frac{D}{d}$ for $\frac{L^3}{l^3}$ in the above equation we obtain

$$R = r\frac{D}{d} \text{ and } \frac{R}{r} = \frac{D}{d},$$

which, expressed in words, will be:

The resistance of the model is to that of the ship directly as their respective displacements.

With regard to the speed, we have, as before $\frac{D}{d} = \frac{L^3}{l^3}$; but $\frac{L}{l} = \frac{V^2}{v^2}$, and by cubing this last equation $\frac{L^3}{l^3} = \frac{V^6}{v^6}$; and inserting this value of $\frac{L^3}{l^3}$ we obtain:

$$\frac{D}{d} = \frac{R}{r} = \frac{V^6}{v^6}, \text{ and } \frac{\sqrt[6]{D}}{\sqrt[6]{d}} = \frac{V}{v},$$

or:

The speed of the model is to that of the ship as the sixth root of their respective displacements.

But although, as now shown, the results from tank experiments upon Mr. Froude's plan, are derived from calculations based upon the assumption that the resistance of the water increases as the square of the velocity, it will be found by examining the resistance curve of any such experiment, that the resistance of the model increases in a ratio, the

exponent of which, although at small velocities generally less than 2, grows larger as the speed increases and soon becomes greater than that figure, rising sometimes to 3 and over, denoting that the ratio of augmentation is not as the square, but rather as the cube of the speed. It may be concluded, therefore, that if experiments with a model could be carried on up to the actual corresponding speed of the ship, the resistance per square foot of the immersed surface would probably be found to be much greater than calculated according to the duplicate ratio. But if from this reason the resistance calculated in conformity with Mr. Froude's law would seem to be too low, it should, on the other hand, be observed that during the experiment the model is immersed to but little depth, and must, therefore, with its whole body in or near the surface, encounter in proportion greater resistance than if more deeply immersed. It is besides a well known fact, proved by the experiments by Colonel Beaufoy, Mr. Froude, and others, that the surface friction of the water increases in a less ratio than the square of the velocity, and also that the ratio decreases with augmented speed.

As consequently elements of various nature enter into the problem of experiments with ship models, it would seem as if the results obtained from such experiments could not be very reliable. The genius of Mr. Froude, however, found a practical way out of the difficulties, which, if not strictly correct, yet brings the conclusions drawn from experiments carefully made according to his system very near the truth. From his experiments upon friction, Mr. Froude ascertained that the amount of the friction of water upon surfaces of various kinds and the law of its augmentation varied not only as to the coefficient, but also, with equal velocity, according to the length of the surface over which the water passed, the friction being greatest for the short surface and smallest for the longest, at least up to the length of 50 to 60 feet, after which, or for a surface of greater length, the coefficient of the friction appeared to remain nearly constant. Thus, at the speed of 600 feet per minute, or 10 feet per second, the friction upon one square foot of a smooth varnished surface two feet long was 0.390 pounds, while, when the surface had a length of 50 feet, it was only 0.225 pounds; and the index of power expressing the law of increase was in the former case 2.00 and in the latter 1.83, which is the same as to say that doubling the velocity increased the friction 4 times for the short surface, but only 3.55 times for the long one. Mr. Froude now proceeded as follows: The amount of friction per square foot of surface was calculated for the various speeds over 600 feet per minute (about six knots), according to the coefficient and exponent for the greater length of surface and the values thus obtained reduced to the corresponding speeds of the model in proportion of the square of the relative velocities. The amount of surface friction of the model thus obtained, would evidently be considerably less than the actual friction at the experiment, calculated according to the greater coefficient and shorter length of the model. If, now, in calculating the resistance of the ship from the resistance obtained at the corresponding speed of the model, according to Mr. Froude's law, as expressed by the equation:

$$R = r\left(\frac{L}{l}\right)^3,$$

(which is in complete accord with the duplicate ratio of resistance), correction is first made by subtracting the difference of the two values of surface friction above mentioned from the actual resistance of the model, it follows that the thus calculated resistance of the ship must be correct as far as regards its surface friction.

But the surface friction of a vessel with small velocity constitutes nearly the whole, and within moderate limits of speed 90 to 75 per cent. of the resistance. It is clear, therefore, that carefully conducted model experiments upon Mr. Froude's plan will, through the ingenious device above referred to, determine this element of a ship's resistance with a high degree of accuracy. But surface friction has little or nothing to do with the form of the vessel, while the remaining elements of the resistance, which in distinction from the surface friction may be termed plus resistance, depends, to its amount as well as to its law of augmentation, entirely upon the model of the ship's hull; and since this may vary in proportions and lines almost infinitely, it follows that its effect upon the resistance is not subject to any general law. It has been already mentioned that the resistance of a model in tank experiments rises, as the speed increases, in a higher ratio than as the square of the velocity; but as the surface friction is governed by a less ratio of augmentation, the higher ratio of resistance, as given by the experiment, must evidently regard the plus resistance. It may be of interest to examine somewhat further the relation of this element of the resistance to Froude's law, and with this object, using the same denomination as before, calling the resistance of the model at v speed r; the resistance of the ship at V speed R; the speeds, dimensions, and immersed area of the model and ship respectively v and V, l and L, and a and A; and let the resistance of the model, r, be composed of m and n, of which m denotes the surface friction and n the plus resistance, each corresponding to M and N, expressing the surface friction and plus resistance of the ship composing its resistance R; then $r = m + n$ and $R = M + N$; and, as before shown, $\frac{R}{r} = \frac{V^6}{v^6}$, and therefore $R = r\frac{V^6}{v^6}$; we shall also have $M = m\frac{V^6}{v^6}$ and $N = n\frac{V^6}{v^6}$, whence:

$$R = m\frac{V^6}{v^6} + n\frac{V^6}{v^6}.$$

The term $m\frac{V^6}{v^6}$ in the last equation will then represent the correct surface fraction of the ship at V speed and the term $n\frac{V^6}{v^6}$ the plus resistance, which would also be correct provided that n increases in the ratio of the square of the velocity. But if its ratio of augmentation is governed by an exponent greater than 2, and calling the excess x: we have the plus resistance per square foot of the model at v speed $= \frac{n}{a}$ and that of the ship $= \frac{N}{A}$. The index of power expressing the law of augmentation being $2 + x$, we shall then have the analogy:

$$\frac{n}{a} : \frac{N}{A} = v^{2+x} : V^{2+x};$$

whence

$$\frac{n}{a} \cdot V^{2+x} = \frac{N}{A} \cdot v^{2+x};\ AnV^{2+x} = aNv^{2+x},\ \text{and}\ N = n\frac{A}{a} \cdot \frac{V^{2+x}}{v^{2+x}}.$$

But $\frac{A}{a} = \frac{L^2}{l^2}$, and as $\frac{L}{l} = \frac{V^2}{v^2}$, $\frac{A}{a} = \frac{V^4}{v^4}$; and substituting this value of $\frac{A}{a}$ we obtain:

$$N = n\frac{V^4}{v^4} \cdot \frac{V^{2+x}}{v^{2+x}} = n\frac{V^{6+x}}{v^{6+x}}.$$

The excess of the ship's resistance over that as obtained according to Froude's law will then be expressed by the difference between these two values of N; or if we call this excess E:

$$E=n\frac{V^{6+x}}{v^{6+x}}-n\frac{V^6}{v^6}=n\left(\frac{V^{6+x}}{v^{6+x}}-\frac{V^6}{v^6}\right);$$

$$E=n\left(\frac{V^{6+x}v^6-V^6v^{6+x}}{v^6\,v^{6+x}}\right),$$

$$E=nv^6V^6\left(\frac{V^x-v^x}{v^6v^{6+x}}\right),\text{ and}$$

$$E=\frac{nV^6}{v^{6+x}}\left(V^x-v^x\right).$$

If we now, for an example, assign some definite values, choosing a vessel of about 8200 tons displacement on 24 feet draught of water, and calling $L=432$ feet; $l=12$ feet; $A=31104$ and $a=24$ square feet; $v=230$ and $V=1380$ feet; $r=1$ pound (composed of $m=0.8$ and $n=0.2$); and $x=1$, in which case n increases as the cube of the velocity:

According to the equation $R=r\left(\frac{L}{l}\right)^3$ we have then the resistance of the ship $=1\times(36)^3=46656$ pounds, composed of $M=0.8\times(36)^3=37324.8$ pounds, and $N=0.2\times(36)^3=9331.2$ pounds; and

$$E=\frac{0.2\times(1380)^6}{(230)^7}(1380-230)$$

$$E=\frac{0.2\times(1380)^6}{(230)^7}1150.$$

Log. 1380=	3.1398791	Log. 230=2.3617278
	6	7
	18.8392746	16.5320946
	16.5320946	
	2.3071800	
Log. 1150=	3.0606978	
Log. 0.2 =	0.3010300−1	
Log. E =	4.6689078	
E =	46656 pounds.	

It thus appears that in this particular case the difference in the resistance of the ship at the speed of 1380 feet per minute, or between 13 and 14 knots, would be exactly equal to the whole resistance, R, calculated according to Froude's law. This can also be easily deduced from the equation, since $V=6\,v$; as by inserting this value of V we obtain:

$$E=\frac{n\,6^6\,v^6}{v^7}(6\,v-v)=\frac{n\,6^6}{v}5\,v,\text{ and}$$

$$E=\frac{0.2\times6^6}{v}5\,v=6^6=46656.$$

The plus resistance (0.2 pounds), which, according to Froude's law, increases to 9331.2 pounds for the ship at the corresponding speed, should, therefore, if governed by the law of the cube of the speed, be equal to $E+N=46656+9931.2=55987.2$ pounds, or considerably more than the whole resistance as calculated according to Froude's law.

We know, however, that this cannot be so, for it has been practically

proved that the calculated resistance according to Mr. Froude's system would, for the moderate speed assumed in the foregoing example, be very nearly correct, and the plus resistance N would, therefore, actually be about 9931.2 pounds. But it is not difficult to explain the cause of this. It should be borne in mind that, in the equations expressing Froude's law, the resistance is assumed to affect equally the whole immersed area of the model and ship, while, in point of fact, the bottom part of the ship encounters far less resistance per square foot than the part near the surface. The portion of the ship's hull at a considerable depth below the surface, encounters but little more resistance than that owing to the surface friction, and it is therefore only the resistance of the portion of the immersed area near the surface of the water that will be affected by the high ratio of augmentation. If we now propose to ascertain, in the example given, how great portion of the ship's immersed surface, supposing its resistance to be governed by the triple ratio of the velocity, would account for the resistance of 9331.2 pounds, Y may represent that area. As the model, with its comparatively small volume, is wholly at the surface of the water, its plus resistance, n, may, without any appreciable error, be considered to be equally distributed over its immersed area, whence its amount per square foot will be $=\frac{n}{a}$. If now the ship itself is supposed to be moving at the same rate of speed, v, as the model, its plus resistance per square foot of the area Y would also be $=\frac{n}{a}$. The whole plus resistance of the ship at the speed v would therefore be expressed by $\frac{nY}{a}$; and as that part of the resistance is assumed to increase in proportion of the cube of the velocity, we have:

$$\frac{nY}{a} : N = v^3 : V^3,$$

whence

$$\frac{nYV^3}{a} = Nv^3, \qquad nYV^3 = aNv^3, \text{ and} \qquad Y = \frac{aNv^3}{nV^3} = \frac{aN}{n}\left(\frac{v}{V}\right)^3.$$

And if we in this last equation assign the proper values:

$$Y = \frac{24 \times 9331.2}{0.2} \times \left(\frac{1}{6}\right)^3 = \frac{223948.8}{0.2} \times \frac{1}{216}; \qquad Y = \frac{223948.8}{43.2} = 5184.$$

It appears consequently that a portion of the immersed area of the ship equal to 5184 square feet, or less than one-sixth of the whole wetted surface, would, with its resistance augmenting as the cube of the velocity, be sufficient to account for the ship's resistance over and above that caused by the surface friction. But this area of 5184 square feet would in the present example, with the vessel of 432 feet length, only embrace a zone extending from the surface of the water to a depth of about 5½ feet.

If it were possible to annul the plus resistance of a ship altogether, thus reducing her resistance to that of the surface friction alone and no more, we should then evidently have arrived at a complete solution of the problem how to find the form of least resistance. From what has

now been said it should be clear that such a body or vessel must be entirely submerged; but as in our present state of knowledge we must yet be confined to the air above the surface of the water, it seems that the road towards improvement, when speed is mainly considered, must clearly lie in the direction pointed out by the foregoing train of reasoning, *i. e.*, to design the vessel so as to diminish as much as possible the resistance in and about the surface of the water.

From what has now been said it should be clear that while with low or even moderate speeds surface friction is of the greatest account, its influence becomes of less importance whenever very high speeds are contemplated; and as the amount of surface friction is directly proportionate to the area of wetted surface, the great importance of having that area as small as possible is evident whenever speed is but of secondary consideration. But when the question of high speed arises the surface friction loses much of its relative weight and the other elements of resistance, which exclusively depend upon the form of the hull, must be more particularly taken into account.

In this connection it may be proper to give here some account of the experiments relating to the speed and power curves accompanying this paper. These curves represent the results from a series of experiments upon Mr. Froude's system with a model like the one now shown, but larger, made from the design of the ship having 10881 tons displacement. The model was made of wood, coated with paraffine and varnished, in order to make it as far as possible like those used by Mr. Froude in his experiments for the British Admiralty, and using the same coefficients of friction. The length of the model was 10 feet, its dimensions being one forty-fifth of those of the ship; the displacement = 0.11941 tons or 267.47 pounds, and the immersed surface = 18.785 square feet.

The resistance of the model, being the mean of a great number of runs at the corresponding speeds, and the therefrom calculated effective horse-powers, were as follows:

Speed.	Resistance of model.	Effective horse-power of ship.
	Pounds.	
At eight knots	0.1880	420.8
At nine knots	0.2330	586.8
At ten knots	0.2840	794.7
At eleven knots	0.3390	1043.4
At twelve knots	0.4015	1348.2
At thirteen knots	0.4690	1706.0
At fourteen knots	0.5400	2115.4
At fifteen knots	0.6245	2621.2
At sixteen knots	0.7235	3239.2
At seventeen knots	0.8390	3991.0
At eighteen knots	0.9720	4895.7
At nineteen knots	1.1200	5954.5
At twenty knots	1.2675	7093.4
At twenty-one knots	1.4535	8541.0
At twenty-two knots	1.6695	10277.4
At twenty-three knots	1.8698	12033.7
At twenty-four knots	2.0423	13715.3

ADVANTAGES OF THIS DESIGN OVER THE COMMON TYPE OF SHIP.

In the memorial presented to the President and to Congress, I have enumerated in ten points some of the advantages of my invention, in comparison with vessels of the ordinary type. Referring to them, I will now add some further considerations appertaining to the subject.

1. The first point, "*that the design makes it possible to combine the finest lines for high speed, with great carrying capacity*, will, I think, be sufficiently apparent by examining the drawings and models presented herewith.

To elucidate this point, the ship of 450 feet length and 23 feet draft may be compared with the steamers Gallia and Arizona, both well-known Atlantic steamships. The Gallia is 438 feet long, and draws 24 feet of water at the load-line. She is therefore, 12 feet shorter, but draws 1 foot more water than the ship of my design, which more than compensates for the difference in length. The Gallia's displacement is 8200 tons, while that of this design is 10881 tons, having thus 2681 tons, or nearly 33 per cent. greater carrying capacity that the Gallia.

The Arizona is 450 feet long, and draws 26 feet of water when loaded. Her length is therefore equal to that of this ship, but she draws 3 feet more water. Yet her displacement is only 9500 tons. The ship upon my plan has therefore, on 3 feet less draft, 1381 tons greater displacement. If she also were loaded to 26 feet draft, her displacement would be 12250 tons, having then 2750 tons greater displacement. In the former case her carrying capacity would be 14½, and in the latter 29 per cent. greater than that of the Arizona.

The ship of 490 feet length, drawing 25 feet of water, has a displacement of 13677 tons, which is 1200 tons greater than that of the Servia, although that ship is 515 feet long and draws 26 feet of water.

But yet these ships, although well designed upon the ordinary plan, and holding their place among the best of ocean steamships of the present day, are what might be termed bluff ships in comparison with the vessel of my design.

2. *The form of the aft part of the immersed hull with its submerged stern, which divides the water horizontally, permits, in the highest possible degree, great sharpness astern, or what is called "a clean run," which is the indispensable condition for high speed.*

It will be seen by inspecting the designs and models that the lower part of the hull terminates astern in a horizontal edge, joining both propeller tunnels, which for some distance form the bottom of the hull. The water passing the widest part of the ship flows above as well as below this portion of the stern, being thus divided in a horizontal instead of vertical direction. The angle of obliquity determining the sharpness of run of this part of the hull must therefore be taken vertically, and it will be at once perceived that it may remain unaltered, whatever width the horizontal portion of the stern may have. The water above the level of the propeller shafts and the horizontal stern is divided vertically in the usual way. This portion of the ship is, as will be observed, very sharp, forming a "clean run," which will permit a perfectly free and easy flow of the water all the way from the middle of the ship astern to the rudder and propellers. The angle of obliquity of the water-line, just above the horizontal stern, is the most obtuse of all, diminishing from this point as the water-lines rise to the load-line, which is the sharpest of all the water lines, its angle of obliquity being the smallest.

It will thus be seen that the greatest bulk of the displacement is in the lower part of the hull at a considerable depth below the surface, where the resistance of the water is the least, developing gradually into the flat stern, which makes sharp lines and small angles of obliquity possible, although the width of the ship amidships at that depth below the water may be very great.

The water-lines above the load-line gradually expand, but are yet very sharp to a considerable height above the water. The fine run is thus maintained, even if the ship should be loaded much deeper than to the load water-line. It is clear that maintaining a fine run, not only in the load water-line, but also to a considerable height above it, will obviate the increased resistance which in ships of the usual form always takes place in a seaway when the ship sets or the sea rises under the counter.

The importance of having a good run in a ship, or sharpness astern, is generally understood, but its enormous influence when *high* speeds are contemplated is perhaps hardly sufficiently appreciated. It has been proved by Colonel Beaufoy and others that an angle of obliquity astern of twenty degrees increases the resistance within moderate speeds over 18 per cent. But few, if any, ships have so small an angle of obliquity at the load water-line; generally it is very much larger, even in ships designed for good speed. It is true that the sharpness increases with the depth below the water-line until at the keel it becomes a straight line, *but the resistance is greatest at the surface.*

3. *The great width of the aft part of the ship's hull, which is a consequence of the submerged horizontal stern, affords ample room for the application of the greatest engine power compatible with the displacement.*

The designs and models show this, I think, so clearly that any further explanation may be superfluous.

4. *The design is eminently adapted for the use of twin screws, as the form of the submerged stern affords a perfect support to the propeller shafts.*

It has been said already that the main object of this invention is *high speed*, which means the application of great power, and for that purpose two propellers, or twin screws, should be used. It has also been shown how, by the adoption of the submerged flat stern, at the greatest possible depth compatible with the displacement and the draft of water, it became possible to have large breadth of beam and consequently great displacement, and yet fine lines and a clean run aft. But in solving that problem another great point was gained, namely, to give a firm support to the propeller shafts for twin screws. As seen on the model, the tunnels for the propellers form the bottom part of the submerged stern; and as these tunnels should be built of very heavy plates, they will add immensely to the strength of this part of the ship.

5. *The propellers act constantly in solid water, undisturbed by the proximity of the stern-post, rudder, and the overhanging part of the stern, as in ships of the usual model. This must cause an economy of power or a corresponding increase in speed.*

That the propellers, by their position, will be enabled to exert their power to best advantage, undisturbed by eddies or broken water from the causes mentioned, will be readily perceived; but with respect to the advantages gained by that position of the propellers, in comparison with their usual place in ships of ordinary model, it may be proper to add some further observations.

Among the advantages of twin screws over the single propeller, so ably set forth by Mr. W. H. White in his paper to the Institution of

Naval Architects, in London: "On the comparative efficiency of single and twin screw propellers," he particularly remarks the greatly increased power developed by the propellers being deeply immersed. Now, it is evident that twin screws may always be more deeply immersed than a single screw of equal power, owing to their smaller diameter. In the Navy Scientific Papers, No. 12 (page 45) some experiments are quoted from a paper of Mr. G. B. Rennie to the Institution of Naval Architects, London. These experiments were made with a small propeller of 1 foot 9 inches in diameter, and showed the following results:

When the propeller just touched the water edge its resistance, at a certain number of revolutions, or the power it developed, was 7 pounds per square inch of the disk area; when immersed six inches deeper the resistance rose to 28 pounds, and to 56 pounds when there was 54 inches of water over the propeller.

In smooth water, when the even motion of the ship keeps the propeller steadily immersed to about the same depth as it was when the ship was in port, it may not appear to make much difference if the propeller, as in most Atlantic line steamers, comes when the ship is loaded to within two feet or even less of the water edge; but in a little sea, causing the ship to begin to pitch, or to have even a very slight longitudinal motion, the upper points of the propeller blades will of course rise to the surface or above it. That, in such case, a very considerable amount of power is lost, needs hardly to be pointed out. But another yet more important cause of detraction from the efficiency of the single propeller is to be found in the disadvantageous position of the propeller, placed, as it is, in front of the rudder, far under the counter where, particularly, while pitching, the water is mostly broken into eddies, in which the propeller has to do its work. But the greatest cause of loss of power arises generally from the want of a clean run at the surface of the water. The angle of obliquity of the load water-line is in most ships very large, frequently forty-five degrees and over, compelling the water to flow along the counter in a curve and enter the disk of the propeller at a small angle instead of in a nearly perpendicular direction, as it ought to do. Mr. Froude estimates the augmentation of resistance from that cause all the way from 40 to 15 per cent. for a single screw ship (see page 164, Navy Scientific Papers, No. 10), and as low as 12 to 8 per cent. for twin screws.

It is not difficult to account for this great increase of resistance and consequent loss of power. The water at the surface following the curve of the ship's side strikes the propeller with less velocity than the water deeper down, which enters the disk of the propeller in a more direct line. But the propeller revolves according to the speed of the ship, that is to say, in conformity to the velocity of the water nearer the ship's bottom, and the blades of the propeller must therefore encounter unequal resistance, as, during the revolution, they pass through layers of water of different swiftness. When the top of the blade passes through these slower currents, the power required to force that water astern with the same velocity as that of the unobstructed free-flowing water nearer the keel must be that much power lost. The thumping noise of the propeller, and its vibration, is mainly due to the same cause. The simple fact is that with most ships the water at the surface, even when going at but moderate speed, forms eddies or dead water about the middle of the stern, and the propeller has to exert a large percentage of its power to suck that water away.

In an experiment made with a working model at the Royal Service Institution, London, a telescopic pipe, passed through the stern, allowed

the water to flow into a compartment in the vessel, which was thus filled in ten seconds; but when the pipe was pushed out to the screw, while propelling the vessel ahead, the suction was powerful enough to empty the compartment in seven seconds, during which operation the vessel lost 19 per cent. of its speed.

It has been mentioned that Mr. Froude found less loss of power with twin screws than with single propellers. This is but a natural sequence of their smaller diameter and consequent deeper immersion where the run is better, or, in other words, the angles of obliquity of the water-lines more acute. But here again comes in another cause of resistance. Any one looking down on the water close to the ship's side, when going at a moderate speed, will notice that the water near the ship's side and for some little distance from it, moves with the vessel. There is always such a current of water with the ship caused by the friction, the velocity of which is, of course, greatest close to the ship. The twin screws in the ordinary type of ship have their position so that the tip of their blades come very near to the side of the ship; at all events near enough to encounter part of the current thus following the vessel, and the effect is similar to that with the single screw, namely, loss of power and vibration of the propellers. That the power absorbed by this current is considerable has frequently been shown, as, for instance, by the circumstance that in paddle steamers greater speed has been gained by cutting away a portion of the floats next the ship's side, the remaining portion, although of considerably less area for applying the engine power, yet giving a higher speed.

These facts are well known; they have been observed and proved by numerous experiments conducted by Mr. Froude and others, and notably so by Mr. Robert Griffith, of London, who has devoted himself almost exclusively to the study of the propeller. During a long course of experiments with working models, he found that with the propeller placed close up to the stern, or to the wedge of the run, as in existing ships, greatly increased resistance and loss of power always took place. But when the propeller was moved further aft away from the dead water always found close to the stern, the speed was increased from 12 to 15 per cent.

But if the augmentation of the speed gained by reducing the extra resistance above spoken of did not even amount to more than 6 per cent., the corresponding economy of power, through diminishing the weight of engines and coal, would amount to a much greater percentage. It may be of some interest to see how great would be the economy of power thus gained; therefore, let—

v represent the speed of the ship before the improvement;
P, the power required to produce that speed;
V, the speed of the improved vessel with the same power;
n, the percentage of speed gained;
p, the power needed to produce the speed v with the improved vessel;

then

$$V = v + \frac{vn}{100} = v\left(1 + \frac{n}{100}\right); \text{ and } V = v\left(\frac{100+n}{100}\right).$$

But as within moderate speeds the resistance is proportionate to the square of the velocity, and, therefore, the power required to produce the speed proportionate to the cube of the speed:

$$P : p = V^3 : v^3, \text{ and } Pv^3 = pV^3;$$

and if for V is substituted the above value:

$$Pv^3 = pv^3 \left(\frac{100+n}{100}\right)^3; \qquad P = p\left(\frac{100+n}{100}\right)^3;$$

$$P\,(100)^3 = p\,(100+n)^3, \qquad \text{and} \qquad p = P\left(\frac{100}{100+n}\right)^3.$$

If, now, $n = 6$,

$$p = P\left(\frac{100}{106}\right)^3 = 0.839\ P;$$

or it appears that it would take less than 84 per cent. of the power to produce the original speed with the improved vessel, equal to a saving of over 16 per cent.

A ship built upon the present design will avoid the greatest part, if indeed not all, of the extra resistance above mentioned. The propellers are much deeper immersed than the single screw, and must therefore always retain a better hold upon the water, while the water-lines are very sharp, with small angles of obliquity all the way up to a considerable height above the surface, thus permitting the water to flow with an even velocity to the propellers. There will consequently be no unequal currents to absorb power or cause vibration, and the propeller blades are far away from the ship's side, beyond the influence of the accompanying current of water caused by the surface friction.

6. *"A vessel of this form will not roll or pitch as much as vessels of the common type, because the body of water over the projecting part of the hull will offer considerable resistance to such motion. Less pitching will also, in a great measure, tend to prevent 'racing' by the propellers partly lifting out of the water; and this greater steadiness of the ship during its progress through the water must economize power or add to the speed."*

It will be perceived by examining the designs that the projecting sides of the ship at a considerable depth below the surface of the water must tend to keep the ship steady in the same manner as bilge keels in an ordinary vessel. The effect of such bilge keels to diminish rolling was well known long ago, but it was only by the direct experiments of Mr. Froude, upon full-sized ships, that actual measurements were made to determine the degree of increased steadiness thus gained; and it was then proved that the bilge keels reduced the rolling from 23 to 11½ degrees, or just one-half. Where now such a result could be gained by bilge keels only about 2 feet deep, much greater effect must be produced by the projecting sides of the hull, which extend 4 feet beyond the load water-line. But aside from such general reasoning, there are other causes susceptible of mathematical demonstration why a vessel of this design must be very steady.

The rolling motion of a ship is governed by the subsurface of the wave passing through the Center of Buoyancy; or, more correctly expressed, the effect of a ship's stability is to keep her upright with respect to this subsurface, or, as it is termed, "the effective wave surface." This effective wave surface is therefore situated just as much below the actual surface of the water as is the Center of Buoyancy; and inasmuch as the steepest slope of a wave, or its greater angle with the horizon near the crest, is to be found at the surface of the water, while the subsurface of every successive layer of water, as the depth increases, gradually becomes more and more depressed, until at a certain depth it becomes a perfect level, it follows that a deep ship with its Center of Buoyancy low down will, as a rule, roll less than one of less draught and

higher Center of Buoyancy; provided that the conditions as to the meta centric height are similar, or not excessive in either. Now, as will be observed, the Center of Buoyancy in this design is exceptionally low down, and as the height of the Meta Center above the Center of Gravity is such as to insure ample stability and easy motions at sea at all draughts of water to which the ship may be loaded, the foregoing reasoning shows that the ship will be exceptionally steady.

But it follows from the great breadth of the hull, as well as from its form, that its Radius of Gyration is very great—greater than in an ordinary ship of equal displacement—and, consequently, the equivalent pendulum, the revolutions of which would keep exact time with the oscillations of the free rolling ship, will also be of exceptionally great height.

The position of the propellers and the great weight of the engines, a considerable distance from the middle line of the ship, will also have the effect of lengthening the Radius of Gyration and make the period of oscillation longer than if there was only a single screw.

From what has now been said it may be concluded that the rolling motion of a ship upon this design will be exceptionally slow, and therefore also very easy.

As to the pitching motion, the same argument presents itself as in rolling, as to the effect of the superincumbent body of water over a portion of the ship's hull to check or diminish the motion. But here the element of speed must be taken into particular consideration. It may be superfluous to observe that the great sharpness of the ship, or the extreme fineness of its entrance and run, while especially favorable for penetrating the seas, is not calculated to permit the bow or stern to be elevated by the meeting waves as easily as a vessel of the common type. The sea, which almost immediately, when such a vessel plunges into it, begins to lift the bow, will have comparatively but little power to do so with a ship upon this plan. Suppose a vessel of the ordinary form riding at anchor in a storm with heavy sea. A wave meeting the ship's bow would quickly commence to elevate it and continue to do so until the Center of Buoyancy (which, changing its position with the movement of the vessel, is forward of the Center of Gravity while the bow is being raised) had passed the perpendicular of the ship's Center of Gravity, at which moment the descending motion of the bow would begin, except for the influence of the weight of the suspended cables at the bow. But with a ship of this design, of about equal size, under similar circumstances, the case would be widely different, because the sharp bow would pass through a considerable portion of the wave before much of its buoyant effect would be felt.

It is clear, therefore, that the pitching motion of a ship of this design would be much less in degree, than for a ship of the common form. But another circumstance must also be taken into consideration.

The longitudinal Meta Centric height of the ordinary vessel, with her, for a considerable distance, nearly parallel sides and full bow, is always very large, and the energy with which she will strive to regain her disturbed stability is consequently also very great, causing the bow, after being raised by the wave, to descend and plunge into the sea with great violence.

In the present ship, with her sharp ends and total absence of any parallel middle body, the longitudinal Meta Center will not be so high, and the longitudinal motion therefore more easy.

Suppose now that the ship, the design of which is presented herewith, and another steamer of common form and power were steaming against

the wind and sea. The ordinary vessel, going at a good speed at the beginning of the gale, before the sea had had time to get up much, would, when meeting a heavy sea, plunge her bluff bow violently into it, then rapidly rise, and so with the succeeding waves the pitching would commence in the usual way, straining the ship with the quick violent motion and heavy blows of the seas, sometimes almost stopping all headway, and "racing" the engines until it becomes necessary to "slow down."

The ship of this design would behave differently. I have shown that her pitching motion would be much less at anchor than that of an ordinary vessel; but this difference between the two ships would be far greater when steaming against a gale. She would raise her bow but little as she passed through the meeting wave, and her great speed would, in connection with the actual velocity of the waves, cause so rapid a change in the position of the Center of Buoyancy that the inertia of the ship could permit only a slight deviation from the horizontal position. Her sharp bow would penetrate the waves with comparative ease, without feeling their shocks in the manner of the common ship. With her deeply-immersed propellers and steady motion there would be no "racing" of the engines, and but little need of slacking the speed on account of the sea.

7. *The rudder (or rudders, if two are used) may be made lighter and have considerably less area than in ships of the ordinary kind, because the stern of the vessel, on account of its form, offers less resistance to lateral motion, thus requiring less power to swing or move it sideways. The resistance to the vessel's progress due to the rudder being proportionate to its surface, it follows also that the diminished area must lessen the resistance and tend to increase the speed.*

This point will need but little further explanation. The effect of the rudder being to move the stern of the ship sideways, it is clear that the resistance to such motion, or the amount of power required to overcome it, must depend upon the length of the vessel and the vertical area that has to be moved laterally, *i. e.*, the longitudinal midship section of the ship; and it will be seen that this area is in the present design considerably less than in vessels of the common form of equal length and draught of water. It should also be observed that the greatest difference in the longitudinal area, as compared with that of a ship of the common form, occurs furthest aft, where, during the swinging motion around the ship's Center of Gravity, the velocity is greatest, and, consequently, most of the power is absorbed.

The resistance to the lateral motion caused by the rudder being thus necessarily diminished for a ship of this design, it follows that its rudder may be of considerably less area and yet develop as much effect as a rudder of greater area upon an ordinary vessel of equal length and draught of water. Or, if both vessels have rudders of equal area, the ship of this design must answer the helm more quickly than the ordinary ship.

8. *Owing to the increasing width of the hull below the load water-line, the ship will stand upright, and may be moved about or go to sea without ballast. Indeed, the more the vessel is lightened the greater becomes the stability, because the Meta Center rises with the greater beam much more rapidly than the Center of Gravity.*

As this subject is of very great importance, the question of stability

being usually one of the first points raised in examining any new design, some additional observations will here be in place.

The statical stability of a vessel, being the moment of force exerted to replace it in an upright position after having been inclined to a certain angle, depends, as is well known, upon the relative position of its Meta Center and its Center of Gravity, the ship being stable or standing upright as long as the Meta Center is above the Center of Gravity, but losing all stability when these two points meet. When the ship is stable and heeled over from the upright position, there are two forces at work endeavoring to raise the vessel to the upright position again, namely, the lifting force of the water, the resultant of which acts through the center of displacement, or the ship's Center of Buoyancy, and the weight of the ship, acting through its Center of Gravity. As the ship is inclined, the form of the displacement is altered and its Center of Buoyancy takes another place than before, while the Center of Gravity of the ship does not change its position. A vertical line through the Center of Buoyancy passes through the Center of Gravity when the ship is upright, but a vertical line through the new Center of Buoyancy in the inclined position does not pass through the Center of Gravity, but intersects the vertical line of the upright position at a certain point, which is the Meta Center. The greater the height of the Meta Center is above the Center of Gravity the greater is the stability, and *vice versa*. If, however, this height is too great, or beyond a certain limit, the ship will be uneasy, or her movement to regain the upright position after being deflected from it, quick and violent, and should therefore be avoided, as well as to have that height too small, which might endanger the safety of the vessel. Experience has proved that this, or the Meta Centric height, ought to lie between 4 and 2, although a much less Meta Centric height is quite common in steamships of the present day, which practice, however, greatly diminishes the safety, as will be more particularly shown hereafter.

The height of the Meta Center relative to the Center of Buoyancy is a function of the moment of inertia of the plane of flotation (surface water-plane) and the displacement, being generally expressed thus:

$$\text{Height of Meta Center above Center of Buoyancy} = \frac{\frac{2}{3}\int y^3\,dx}{D};$$

in which y is the varying half breadths of the plane of flotation and D the displacement.

By inspecting this formula, it becomes evident that if the plane of flotation has no breadth at all, that is to say, if the ship were entirely submerged, she would have no stability, except if the Center of Gravity were situated below the Center of Buoyancy, as in the case of a lifeboat.

It is also clear from the above algebraic expression that whenever y, or the half breadth, increases, the length and depth of the vessel being unaltered, the height of the Meta Center increases, since y^3 increases more rapidly than D; and *vice versa*, whenever y decreases, the height of the Meta Center diminishes, because in that case y^3 decreases more rapidly than D.

By inspecting the present design, it will at once be seen that the half breadth of the load water-plane always increases, whether the ship is lighter or loaded deeper than to the load water-line.

It will be perceived that this is entirely contrary to the conditions of the ordinary type of vessels, in which, when light, the area of the

plane of flotation and its moment of inertia generally is much less than when the ship is loaded. And this is also the case when such a ship is loaded deeper than to the load-line, because the ship's sides almost invariably incline inwards, or "tumble home" to greater or less degree.

It will readily be understoood that, as the Center of Gravity in a vessel of the common form rises when the ship is lightened by taking cargo or coal from the lower part of the hull, while the Meta Center does not rise, or at all events cannot rise as rapidly as the Center of Gravity, these two points will meet when a certain amount of weight is discharged or consumed, and then the ship must capsize; unless precautions have been taken, by ballast or weight of some kind in the lower hold to keep her upright.

Accidents of this kind, which are but too frequent, cannot possibly happen to a ship of this design.

Again, if an ordinary vessel is loaded deeper than to the load-line, the initial stability rapidly decreases, since not only the moment of inertia of the plane of flotation diminishes, but the displacement at the same time increases. In other words, the nominator in the expression

$$\frac{\frac{2}{3}.\int y^3\, dx}{D}$$

decreases while the denominator increases; and the diminished stability can only be made good by greater proportionate weight in the bottom or lower part of the hull.

In a ship of this design, with expanding sides, when loaded deeper than to the assumed load water-line, the area of the plane of flotation and its moment of inertia increases, thus counteracting the effect of the augmented displacement to diminish the initial stability.

Referring to the synopsis of calculations as given hereafter, it will be seen that the ship of 450 feet length and 10881 tons displacement on 23 feet draught, has a Meta Centric height of 3.458 feet above the Center of Gravity when the ship is loaded ready for sea, while when lightened to 14 feet draught, supposing her to have no cargo, coal, stores, water, or ballast, and no water in the boilers, but otherwise completely fitted and fully rigged, the height of the Meta Center above the Center of Gravity would be 5.060 feet; and if we suppose that every movable weight, such as engines and boilers, &c., were taken out of the ship, leaving the empty shell of the hull, but still being fully rigged with all her top-hamper aloft, we should find that the Meta Centric height above the Center of Gravity had increased to 11.389 feet.

The larger ship of 490 feet length and 13677 tons displacement on 25 feet draught, having, then, besides a full complement of passengers, 3200 tons coal and 611 tons of express cargo, has in that condition her Meta Center 3.616 feet above the Center of Gravity. And when light, having no coal, cargo, stores, or ballast and no water in the boilers, but yet fully rigged, her draught of water being then 15.5 feet, the Meta Centric height is much greater than in the loaded condition, being 5.895 feet; while, if the engines and boilers were also supposed to be taken out, reducing the draught to 10.43 feet, the height of the Meta Center above the Center of Gravity would be not less than 13.211 feet.

The ship will have room for her complement of coal in her coal bunkers and the lower hold below the orlop deck, and as the coal is consumed during the voyage the weight will therefore be taken from the lower part of the hull near the bottom, having consequently the greatest possible effect upon the stability. If now the ship, when leaving port were

loaded to her load water line on 25 feet draught, and assuming that at the end of her voyage she had consumed 2500 tons of coal, in which condition her draught of water would be 20 feet, the height of her Meta Center above the Center of Gravity would, under such circumstances, be yet 2.981 feet.

It is probably superfluous to observe that few, if any, vessels of the ordinary type can stand upright if thus handled. In order to preserve barely enough stability to be termed "safe," with great elasticity given to the word, after being lightened by consuming the coal, it has become an almost universal practice to carry water ballast, sometimes in separate tanks, but mostly in a double bottom, or in the space between the frames of the ship, into which the water is admitted and afterwards pumped out when not wanted. But besides this many steamships must carry a great deal of permanent ballast: and as this is equal to a direct loss of so much freight that otherwise might have been earned, it is only too probable that this permanent ballast is not often any too great. It need hardly be said that this want of natural stability in the ordinary type of steamships is a source of very great danger, for which water ballast and scantily apportioned permanent ballast are at best but unsatisfactory palliatives.

If it could be accurately known how many vessels, steamships in particular, which have never been heard from, were lost from this cause of insufficient stability, the list would assuredly be a long one. But this subject, although none can be of greater importance, involving, as it does, the question of life and death to all those who happen to be on board of a vessel, the design of which is faulty in this respect, has scarcely received the attention which it demands.

With the fashion of building extremely long and narrow ships, under the erroneous impression that such excessive proportions would cause increased speed and give greater carrying capacity, the vital point of stability came gradually to be more and more lightly considered, until there are vessels now built having no initial stability at all when launched; and which therefore, from that very moment, can only be kept from capsizing by having a lot of ballast in the bottom. It is clear that even such ships may acquire stability enough by the weight of the cargo or by a quantity of permanent ballast, but their safety must always depend upon the manner of stowing the load, and some carelessness in that respect, which unfortunately is only too apt to happen, may be the cause of serious disaster. Two recent calamities of this kind attended with great loss of human lives, of which we have accurate knowledge simply because they happened to take place while the vessels were in port, furnish conclusive evidence upon this point: the capsizing and sinking of the steamer Daphne immediately upon being launched from a Glasgow ship-yard, causing the death of 124 persons, and the foundering of the magnificent steamship Austral, in the harbor of Sydney, Australia, by which 5 persons lost their lives.

The inquiries held upon these disasters as published in the Engineering, London, of August 24 and 31 and October 5, 1883, throw a vivid light upon the subject, disclosing facts, which should loudly call attention to what is really a great public danger.

It is indeed to be hoped that now, since the true state of the matter has been given to the public by publishing the reports in a few periodicals, some additional care may be taken in designing new ships; but there are thousands of vessels now afloat partaking in greater or less degree of the same conditions which sent the Daphne and the Austral to the bottom.

In the case of the Daphne, Sir E. Reed was appointed by the British Government to conduct the inquiry, and his report is so remarkable, coming as it does from an authority that will hardly be questioned, that I deem it proper to give some extracts from it. It was shown that the Meta Centric height was only 4 inches, which, of course, was altogether insufficient; and also, surprisingly enough, that English ship-builders had not, before that accident, ever thought of investigating the conditions of stability at very light draught, as at launching, owing to the apparently general impression that as long as there was any statical stability at all when the vessel was upright, there was no danger of capsizing.

Sir E. Reed says:

It would be well, doubtless, as the event has proved, for the builders of the Daphne to have made an exception of this vessel by calculating before the launch, not only the height of the Meta Center, which is often done, but also, as approximately, the height of the Center of Gravity, which is much less often done before launching.

And with regard to the subject generally, he continues:

The general belief that a high-sided ship, having some initial stability, will, as she inclines, gather large additional stability and will retain some, even at very large angles, has exercised a widespread influence on modern mercantile ship-building, and has greatly encouraged people to be satisfied with very small initial stability, in some cases with none at all, and even less than none. Many steamships of large tonnage have been built of late years for influential steamship companies and other owners, which ships are totally incapable of floating upright without the aid of ballast or of cargo, and which cannot be unloaded in dock without being held upright with hawsers attached to the shore.

Such ships, even when capable of floating unballasted without capsizing, can only do so by lolling over at large angles of inclination and there finding a position of stable equilibrium. When carefully watched over and stowed with suitable cargoes, these ships can usually be made safe at sea, and sometimes even safer than ships with larger initial stability but less range, a circumstance to which undue prominence has perhaps been given, and which has diverted many from the grave elements of danger, which more often are associated with small initial stability. There is not the least doubt, however, that the very small initial stability given to many modern mercantile steamships—given in the belief that much more is sure to be gained as the ship inclines (within large limits)—has resulted in the capsizing of many ships at sea and in grave danger to many that are still afloat; not in the same manner, because not in the condition as to lightness, as the Hammonia* and Daphne, but from other not less real deficiencies.

Sometimes such vessels are brought into a condition of apparent safety by the stowage of their own coal, but as the coal is consumed their stability diminishes, they capsize, disappear, and the word "missing" is recorded against them in an official return. No means exist, notwithstanding all our shipping legislation, for insuring that the facts will be brought to light—indeed, at the official inquiry, which follows under the present conditions, the question of stability may not even be mentioned. As the stability of a ship is often an intricate matter which can be effectually controlled only by close and careful calculations, and as no Government department is at present charged with the duties even of collecting, recording, and making known those dimensions and particulars of ships which determine their stability, the matter must be left to right itself.

The Austral disaster took place under circumstances widely different from those attending that to the Daphne. The Austral, a new ship of 474 feet length and 48 feet beam, one of the fastest and most commodious steamships afloat, comparable in these respects to the Alaska and Oregon, and built by the same renowned builders, was lying at her moorings in Sydney harbor, on the evening of November 10, 1882, laden with 190 tons of iron in the main hold, 1612 tons of coal in her bunkers, 111 tons of water ballast in one of the ballast tanks, and 70 tons in the

* The Hammonia, another steamship built by a Glasgow ship-building firm, also capsized when being launched, a year before the Daphne disaster, and from exactly similar cause.

fresh-water tanks, altogether not less than 1883 tons. She was taking in coal from a collier alongside, through the ports, which were five feet above the water, when she listed over so that the water entered through the coal-ports, whereupon she, of course, heeled over more, filled rapidly, and sunk. The disaster was so sudden that the purser and four seamen were lost in the ship.

At the subsequent inquiry upon this catastrophe, it was proved that when light, on a mean draught of 17½ feet and a displacement of 5850 tons, the Austral has a *minus* Meta Centric height of 9½ inches. That is to say, she has then just that much less than no stability at all, and would consequently capsize and turn bottom up immediately without a sufficient quantity of ballast. When laden to her load draught of 26½ feet, having then, with a homogeneous cargo and 2530 tons of coal in bunkers, fresh water in tanks and all stores on board, a displacement of over 10000 tons, her Meta Centric height is 1.26 feet. It was also said at the inquiry that "supposing all the coal to be consumed, she would still, by a proper use of the water ballast, retain a Meta Centric height of 1.16 feet." Now, in the event of the coal being consumed, she may, as stated at the inquiry, by making "a proper use of the water ballast," retain sufficient stability to be considered safe; but if, under such circumstances, from some cause or other, there should be a hitch in the proper use of the ballast tanks, the ship would inevitably capsize and sink.

But disasters similar to that which happened to the Austral may occur to the great majority of steamships afloat, and if the necessary care in the proper use of the ballast tanks should happen to be wanting at sea, the consequence is only too clear. This statement is not exaggerated. What happened in the two cases just mentioned, may happen again, not only to a few, but, as can be proved by proper calculations, to by far the great majority of mercantile steamships afloat. That in this state of things there is lurking a great public danger, is but too evident, and when, in the words of Sir Edward Reed, "the matter must be left to right itself," it is only to be hoped that proper steps to redress the evil may not be too long postponed.

The root of this evil is clearly to be found in the prevailing type of ships. There must, aside from all other considerations, such as of speed, carrying capacity, &c., exist something radically wrong in the design of all these vessels, if the lives of those on board, not to speak of the money value of ship and cargo, may be put into such fatal jeopardy by any possible carelessness, or omission of duty, of somebody connected with the ship. The captain of such a vessel has already enough of responsibility in looking out for the proper navigation of his ship and thousands of other important matters, without being saddled with additional anxieties as to whether his orders about the admission of water into the ballast tanks, at the proper time, have been attended to.

This subject is indeed of such paramount importance, that a ship possessing absolute safety in point of stability at sea, under all possible contingencies, even if she were inferior in other respects, ought still to be preferred to another vessel manifestly deficient as to that vital condition.

A ship upon the present design must be absolutely exempt from any possible risk connected with the stability. She will need no ballast of any kind, because she will actually acquire additional stability by being lightened—a fact in direct opposition to the property of the ordinary vessel. Nor will she suffer any diminution in her earnings by having a great portion of her carrying capacity taken up by ballast that pays no freight.

9. *The use of two propellers, having their shafts effectually supported and protected within the ship's hull, must add greatly to the security against accidents at sea, such as might disable a vessel with only one propeller, or where the propeller shafts, as usual with twin screws, run outside of the ship.*

Upon this point there remains but little to be added to what has been already said. It may, however, be proper to call additional attention to the frequent recurrence of accidents to the propeller shafts in large ocean steamships, and the consequent danger to the safety of the vessel. That such accidents are always of a dangerous nature need hardly to be pointed out. The breaking of the crank shaft of the Aurania, the splendid new steamship of the Cunard line, and the more recent accidents from similar cause, which disabled the Britannic and Germanic in mid-ocean, afford striking examples of the risk incurred. Of these ships the Aurania could be towed into New York Harbor within a few hours, but the other two ships had to perform long and perilous voyages under sail, which in the event of heavy weather would have become hazardous in the extreme. And, no doubt, if the truth could ever be known, the loss of many steamers now recorded as "missing" would rightly be attributed to this cause.

A ship of this design having two propellers is, of course, not entirely exempt from possible accidents of this kind. But it will be conceded that the danger will be immensely reduced, since it is exceedingly unlikely that both shafts will break at the same time, or during the same trip; and it should also be observed that a ship of the present design, with engines of such great power, would, with only one propeller, make a speed equal to the fastest steamship now afloat, and thus, after all, need but a short time to reach her destination.

10. *The arched form of the hull, with the projecting sides below water, and the general absence of any plane surface exposed to the sea, admits of very great strength of construction, and with judicious application of water-tight compartments such a vessel may be made exceedingly strong, offering the best possible security against the violence of the sea and the perils of collision.*

The truth of this will need no other demonstration than the well-known fact that an arched form of structure possesses generally the greatest elements of strength for equal weight of material. The application of this general principle is adhered to throughout this design, and must, under the conditions of good material and workmanship, result in a vessel of exceptional strength. If, with regard to the upper portion of the ship, from about the load water line upwards, it might be argued that the concave form of the ship's side is not well calculated to withstand the effect of a striking sea, the answer would be, that the effect of a force acting upon the concave ship's side is at once transmitted through the beams to the opposing convex side, and the two arched surfaces together possess a greater degree of strength to withstand the force than two parallel, or nearly parallel, ones, as in the ordinary style of ship, where the sea meets a slightly convex surface, which is but feebly supported by the slightly concave surface opposite.

It may, besides, be observed that there can be no valid reason why, if sufficient strength can be given to the outward flaring ship's side at the bow, so commonly used, where the sea is expected to strike, as it also generally does, with the greatest force, the outward bend, or the "flare" of the side, may not be continued to the middle or throughout the whole length of the vessel.

Such an outward bent ship's side may not, to any appreciable extent,

"keep off the spray" in ordinary weather, but although it evidently can have but little effect "to keep the ship dry" in a sea-way, neither does it facilitate or, as it were, invite the sea to roll inboard over the top of the rail, as does the "tumble home" ship's side. The advantages of such an expanding ship's side in giving more inward room and greatly increased stability are, however, obvious, while they must, on the other hand, necessarily be accompanied by greater weight of material in proportion to the increased deck surface.

The construction of the submerged stern need not make any exception from the general rule as to the exceptional strength that may be given to a vessel of this design. It must be borne in mind that the design contemplates iron or steel as the material of construction, and there cannot then exist any cause why an abundant, or, if so desired, even a superfluous degree of strength may not be given. It has already been mentioned that the tunnels for the propeller shafts, which constitute a large portion of the submerged stern, should be constructed of heavy plates of very great strength, strong enough in fact to support, in conjunction with the other part of the structure, any strain to which that part of the vessel may possibly be exposed. Such an extraordinary strain may evidently occur during a severe storm with heavy sea, when the ship's motions may be of exceptional degree; but it should be remarked that even under such circumstances the ship's stern must, during an upward motion, when the greatest strain will occur, always be accompanied by the uprising or following water from below, neutralizing to a great extent the imposed strain.

But additional strength may be given to this part of the vessel by longitudinal bulk-heads, extending along the tunnels through the submerged stern, and forming part of a system of longitudinal bulk-heads, or water-tight compartments throughout the whole length of the ship, thus imparting to the vessel an immense strength and rigidity. A great number of transverse bulk-heads will also divide the ship into water-tight compartments, and these, in connection with the longitudinal water-tight bulk-heads, should make the vessel not only extraordinarily strong, but practicably almost unsinkable.

EXPLANATION OF DRAWINGS AND MODELS.

The designs and models presented herewith differ from each other with respect to the rudders, the smaller ship having two such; and there is also a slight variation in the form of the bow. But both vessels have equally sharp lines, or the same fineness of entrance and run. The length of the small ship is 450 feet, greatest breadth 66 feet, and draught of water on the load line 23 feet, having then a displacement of 10881 tons. The larger ship has a length of 490 feet, 68 feet greatest breadth of beam, and 25 feet draught of water on her load line, with 13677 tons displacement. A schedule of dimensions and other data, together with a synopsis of the calculations, are given hereafter.

The spacious height between decks and the great width of the ship afford the requisite conditions for healthy and comfortable arrangements of cabins and state-rooms, in the fittings of which some improvements upon the usual custom might be made. As, however, any details of construction and interior fittings are extraneous to the purpose of this paper, the suggestion is here made only to point out the superior capabilities of the ship in this respect. There would be ample room for 600 first class, and 1000 second and third class passengers.

This design being for an Atlantic Mail and Passenger steamer of very high speed, she is to have very powerful engines, the weight of which, together with the coal, will occupy the greatest portion of the carrying capacity. With a complete number of passengers there will only be room left for about 600 tons of mail, specie, and other express cargo, provided that the ship is not loaded deeper than to 25 feet draught. But in all probability she would be loaded deeper than to the assumed load line when leaving port, as is customary, and if loaded to 26 or 27 feet, that would add respectively 500 or 1000 tons more cargo.

As the design especially regards the hull of the ship no details will be here given as to the engines. In this respect, however, there is no novelty contemplated, but to use the ordinary three-cylinder compound engines, which are now generally adopted in large ocean steamers.

The engines on each propeller-shaft are assumed to develop 10500 indicated horse-power, being an aggregate of 21000 indicated horse-power. The steam to be supplied by fourteen double-ended boilers of 16 feet diameter and 17 feet length, having a heating surface of over 60000 and a grate surface of 2500 square feet. The propeller to have 31 feet pitch and make, with full power, 80 revolutions per minute.

With this power the average sea speed of the ship may be expected to reach 21 knots. In calculating the speed reference will be had to the model experiments upon Mr. Froude's system, before spoken of, and the accompanying speed and power curves. It should be observed, however, that the reliability of all calculations as to the speed of steamships depends upon the proportion between the effective and the indicated horse-power, which proportion will vary for engines of different design and workmanship.

The loss of power, or the difference between the effective and the indicated horse-power, was classified by Mr. Froude as follows: (1) Augmentation of the ship's resistance by the propellers acting in the manner of a pump, as already described, sucking the water away from the imperfect run of the ordinary ship; (2) friction of the screw-blades; (3) friction of the engines running light; (4) additional friction of the engines according to the load under which they are working; and (5) the working of the air and feed pumps.

About ten years ago Mr. Froude estimated the total loss of power arising from these causes to about 60 per cent., thus assuming the effective horse-power to be only 40 per cent. of the indicated. But since then great improvements have been made in marine engines, and it is now usual, in model experiments upon Mr. Froude's system, to allow 52 per cent., or even more, as the ratio of the effective to the indicated horse power; and a much higher percentage, fully 60 per cent., is now not unusual for ocean steamships with engines of the vertical inverted cylinder type, while in torpedo boats upwards of 75 per cent. has been reached. It has been stated already that Mr. Froude estimated the increased resistance from the action of the screw, placed as usual in ordinary single screw ships in front of the rudder close to the ship's stern, all the way from 20 to 40 per cent. of the total resistance; and he also found from his experiments, as stated in W. H. White's Manual of Naval Architecture, page 551, that when the single screw was placed one-third or one-fourth of the extreme breadth of the ship further aft, clear of the stern, the increase of resistance from the sucking action of the screw was only one-fifth of that produced in its ordinary position. As now in the ship of this design the propellers are placed in the most favorable position, not only with respect to their being far astern and free from the influence of the eddies and currents of different velocity common to ordinary ships, but also on account of their deeper immersion and consequently much greater efficiency, it may, from these reasons in connection with the late improvements in marine engines, be fairly assumed that the ratio of the effective to the indicated horse-power will not be less than 62 to 100.

But before considering the speed that will be attained by this ship as derived from the model experiments upon Mr. Froude's system before described, it will be proper to refer to other methods commonly used in calculating the speed of vessels, and among these I select that of Professor Rankine as most generally accepted. Having come to the conclusion that the principal element of resistance to a ship's progress through the water consisted in the surface friction or "frictional eddies," the aggregate amount of which must depend upon the immersed area, it was, however, evident that calculations based upon such considerations alone, could not give correct results if no account was taken of the form of the vessel. A vessel with full lines, or "bluff" bow and stern, would evidently have less immersed area than one of equal displacement with finer lines, designed for high speed, and the surface friction of the former vessel would therefore be less than that of the latter, notwithstanding that, owing to the form of the hull, the actual resistance would be greatest for the full built ship. If, however, an imaginary immersed surface were assumed, of greater area than the actual one, and the surface friction calculated accordingly, it is clear that a correct result could be obtained. The proper ratio of this assumed surface, or the "augmented surface," as it is termed, to the real one, would naturally depend upon the lines and form of the vessel, and Rankine's investigations to determine this ratio led to the following equation:

$$\text{Augmented surface (S)} = s\,(1 + 4\ \text{sine}^2\ \varphi + \text{sine}^4\ \varphi),$$

in which s is the actual immersed surface and φ the mean angle of obliquity at the bow. The term $1 + 4\ \text{sine}^2\ \varphi + \text{sine}^4\ \varphi$ is called the "coefficient of augmentation." From this equation Professor Rankine derived his formula for calculating the speed:

$$v = \sqrt[3]{\frac{C \times \text{I. H. P.}}{s\,(1 + 4\,\text{sine}^2\,\varphi + \text{sine}^4\,\varphi)}},$$

in which v is the speed of the ship in knots, s the immersed surface, I. H. P. the indicated horse-power, and C a coefficient according to the kind of immersed surface, being 20000 for an iron bottom and 21000 for a coppered one.

If we now consider this formula, substituting 20000 for C, we have:

$$v = \sqrt[3]{\frac{20000 \times \text{I. H. P.}}{s\,(1+4\ \text{sine}^2\ \varphi + \text{sine}^4\ \varphi)}},$$

and

$$v^3 s(1+4\ \text{sine}^2\ \varphi + \text{sine}^4\ \varphi) = 20000 \times \text{I. H. P.}$$

And if we now assume the immersed surface to be 20000 square feet, the speed one knot and the angle of obliquity, $\varphi, = 0^\circ$, in which case there would be no difference between the actual and the augmented surface, there being no vessel but only a surface under consideration, and insert these values in the last equation, we obtain:

$$20000 = 20000 \times \text{I. H. P., and I. H. P.} = 1.$$

It appears, consequently, that according to this formula it would take one indicated horse-power to propel a surface of 20000 square feet through the water, and as in this case there could be no other resistance than the friction, it is evident that the surface friction at the speed of one knot, as assumed by Rankine, was for 20000 square feet of surface, just sufficient to absorb one indicated horse-power. The amount of that friction is found by the equation: $\text{I. H. P.} = \frac{v\,\text{R}}{33000}$, in which v is the speed in feet per minute, and R the friction. I. H. P. being equal to 1, and the speed one knot, we have then $33000 = 101.3\ \text{R}$ and $\text{R} = \frac{33000}{101.3} = 325.7$. And this amount divided by 20000 gives the indicated surface friction for 1 square foot of surface $= \frac{325.7}{20000} = 0.01628$ pounds.

From what has been now said it follows that a vessel having an augmented surface, according to Rankine's formula, of 20000 square feet, would, at the speed of one knot, have an indicated resistance of 0.01628×20000 pounds, and require one indicated horse-power to be propelled at that speed. For another vessel with the augmented surface S, the indicated resistance at one knot speed would be $0.01628 \times \text{S}$. Assuming the friction resistance to increase in the ratio of the square of the velocity, the indicated resistance of the latter vessel at the speed v would be equal to $0.01628\ v^2\ \text{S}$, and the indicated horse-power required for that speed would be found by multiplying the indicated resistance by the speed in feet per minute, and dividing the product by 33000; or,

$$\text{I. H. P.} = \frac{0.01628\ v^2\ \text{S} \times 101.3\ v}{33000},$$

and

$$\text{I. H. P.} = \frac{0.01628 \times 101.3\ v^3\ \text{S}}{33000}.$$

This is Rankine's formula, only differently expressed, as will be seen at once; for from the equation we have:

$$33000 \times \text{I. H. P.} = 0.01628 \times 101.3\, v^3\, \text{S},$$

$$v^3 = \frac{33000 \times \text{I. H. P.}}{0.01228 \times 101.3\ \text{S}} = \frac{33000}{0.01628 \times 101.3} \times \frac{\text{I. H. P.}}{\text{S}},$$

$$v^3 = 20000 \times \frac{\text{I. H. P.}}{\text{S}} = \frac{20000 \times \text{I. H. P.}}{\text{augmented surface}},$$

and

$$v = \sqrt[3]{\frac{20000 \times \text{I. H. P.}}{s\,(1 + 4\,\text{sine}^2\,\varphi + \text{sine}^4\,\varphi)}}.$$

We know that Mr. Froude, through his exhaustive experiments in latter years, determined the actual amount of the friction upon surfaces of various kinds at a velocity of 600 feet per minute, and that for a surface of 50 feet length, having about the same friction as an iron ship, it was 0.250 pounds per square foot; and calculated from these data, according to the ratio of the square of the velocity, we find the coefficient of friction at one knot speed=0.007 pounds. Comparing this with the coefficient, 0.01628, we find that the effective horse-power absorbed by 20,000 square feet of surface, at the speed of one knot, must be proportionate to these numbers, or

$$\text{E. H. P.} : 1 = 0.007 : 0.01628,$$

whence the effective horse-power is equal to 43 per cent. of the indicated. Now, as this was not far from the actual proportion of effective and indicated horse-power of marine engines generally, before the improvements of later years, it follows that Rankine's formula will give practically true results for vessels having the above ratio of its effective and indicated power. But it also appears that with modern engines, giving greater percentage of useful power, Rankine's formula will give the indicated horse-power too high, or, *vice versa*, the speed too low.

This will also be found to be the case with most modern steamships. As an example may be cited the steamship Charles V, built in 1880 by Messrs. Inglis, in Glasgow, the particulars of which were published in the "Engineering" of October 1 of that year. On the trial trip she made 15.11 knots with 2062 indicated horse-power, while Rankine's formula gives for that power a speed of only 13.93 knots, there being a difference of 1.18 knots; or the actual speed proved to be over 8 per cent. higher than as calculated according to Rankine. And some of the new, large, and powerful Atlantic steamships showed even a greater difference at their trial trip. The higher speed thus now obtained for a certain indicated horse-power by steamships lately built is mainly due to the improvements in the engines, and it would almost seem as though the speed of these ships, calculated according to Rankine's formula, would come very near their average sea speed.

But there is yet another important cause why the above formula will give the speed too low or the indicated horse-power too high, the mention of which should not be omitted. It will be seen by examining the equation that the coefficient of augmentation affects the whole wetted surface of the ship, while, evidently, two or more vessels having exactly similar entrance and run, and consequently the same coefficient of augmentation, may have such form amidships that the difference in their

respective resistance will be equal to the difference in surface friction only. With long and narrow ships, having parallel middle bodies of great length, there was from the wave theory, first so admirably demonstrated by Scott Russel, good reason why the whole immersed surface should be thus augmented. But with ships of better form for high speed, having little or no middle body at all, that is to say, where the entrance of the vessel ends just where the run commences, as in the present design, there will be no waste of power in creating the series of oblique divergent waves, the formation of which is, with the ordinary ship, a cause of permanent resistance. And from this reason it is clear that Rankine's formula will, for a ship of this design in particular, give considerably less speed for any given power than what may reasonably be expected.

The limit of this paper will only permit the brief account now given of Professor Rankine's method of calculating the speed and indicated horse-power of steamships, which, as the result of profound scientific research, will always maintain a high rank.

The calculation according to Rankine's formula of the speed of the larger ship, the design of which accompanies this paper, is as follows:

$$\text{Immersed surface} = 44660 \text{ square feet} = S;$$

$$\text{Mean angle of obliquity} = 7^\circ = \varphi;$$

$$v = \sqrt[3]{\frac{20000 \times \text{I. H. P.}}{s\,(1 + 4 \text{ sine}^2 \varphi + \text{sine}^4 \varphi}};$$

$$\text{sine } 7^\circ = 0.12186; \qquad \text{sine}^2 \varphi = 0.01485; \qquad \begin{aligned} 4 \text{ sine}^2 \varphi &= 0.05740 \\ \text{sine}^4 \varphi &= 0.00022 \\ &\ 1.00000 \\ \hline \end{aligned}$$

$$\text{Coefficient of augmentation} \ldots\ldots = 1.05762$$

$$\text{Augmented surface} \ldots\ldots = 44660 \times 1.05762 = 47233$$

$$v = \sqrt[3]{\frac{20000 \times 21000}{47233}} = \sqrt[3]{8892} = 20.72;$$

or

$$\text{Speed} = 20.72 \text{ knots.}$$

According to the wave theory of Mr. Scott Russel, the proper limit for the speed of a ship is expressed by the equation:

$$V = \sqrt{L_1 + L_2};$$

in which V is the speed of the ship in knots and L_1 and L_2 the respective lengths of entrance and run. Applying this equation to the ship of this design, in which $L_1 + L_2$ is equal to the whole length of the ship, or 490 feet, we obtain:

$$V = 1.03 \sqrt{490} = 1.03 \times 22.136 = 22.8 \text{ knots.}$$

Referring now to the model experiments upon Mr. Froude's system and the resistance and power curves relating thereto, which accompany this paper, it will be remembered that they were obtained from experiments with a model of the smaller ship. The design of the larger ves-

sel was recently made, and there has been no opportunity for such experiments with a model of that ship. The designs of these two vessels are, however, similar as to lines and fineness of entrance and run, and it may therefore be assumed that the difference of their resistance will be equal to the difference of their surface friction. The larger ship has 6620 square feet greater immersed surface than the smaller one. In calculating the effective horse-power for the larger ship from the resistance curve of the smaller ship's model, say for the speed of 22 knots, the friction on 6620 square feet of surface at that speed should be added to the resistance of the smaller ship as obtained by the equation $R=r\left(\frac{L}{l}\right)^3$. The friction at the speed of 22 knots, calculated according to the coefficient and index of power determined by Mr. Froude, is 2.4297 pounds per square foot, which, multiplied by 6620, gives 16084.6 pounds. By measuring on the resistance curve of the model, or referring to the table, it will be found that the resistance, r, of the model at the corresponding speed was 1.6695 pounds, which, inserted in the above equation (in which $L = 450$ and $l = 10$), gives:

$R = 1.6695 \times (45)^3$	$= 152133.2$
Adding the friction on 6,620 square feet	$= 16084.6$
Resistance of the larger ship . . .	$= 168217.8$ pounds.

And the equation $E.\,H.\,P. = \frac{VR}{33000}$ gives:

$$\text{Effective horse-power} = \frac{168217.8 \times 2229.3}{33000} = 11364.$$

The same result will, of course, be obtained by adding the E. H. P. corresponding to the greater surface friction for the larger ship to the E. H. P. for the smaller one at 22 knots' speed. By measuring on the power curve, or referring to the previous table, that power is found to be 10277.4, and the E. H. P., corresponding to the augmented friction, obtained by the equation: $E.\,H.\,P. = \frac{RV}{33000}$ is $= \frac{16084.6 \times 2229.3}{33000} = 1087$, which, added to 10277, gives the E. H. P. for the larger ship $= 11364$, as before.

The ratio of the effective to the indicated horse-power being, as before assumed, as 62 to 100, the indicated horse-power required for a speed of 22 knots will then be equal to

$$\frac{11364}{0.62} = 18329.$$

For a speed of 18 knots, the smaller ship, as found by the power curve, requires 4895.7 effective horse-power. The friction on 6620 square feet of surface at that speed is 11141 pounds, which demands 614.8 E. H. P., and the effective horse-power required by the larger ship for 18 knots' speed will therefore be $= 4895.7 + 614.8 = 5510.5$. The indicated horse-power would then be

$$= \frac{5510}{0.62} = 8888.$$

As the engines of only one propeller will develop 10500 indicated horse-power, it follows that in case of an accident happening to one

propeller shaft, the remaining propeller would still give a speed of over 18 knots.

The full engine power on both propellers being 21000 indicated horse-power, while the power required for a speed of 22 knots is, as shown above, 18329 I. H. P., a yet higher speed will probably be attained in smooth water with full engine power. This speed, according to the curves aforesaid, would be 22.6 knots, and an average sea speed of about 21 knots may consequently be expected.

In examining these designs, it may appear as though the immersed surface would be considerably increased by the submerged stern. It has been shown in the foregoing that, with low speeds, the surface-friction constitutes the greatest part of the resistance, and the question of more or less wetted area must, therefore, in such cases, be of great importance; but when high speeds are contemplated, that importance becomes less conspicuous, while the other elements of resistance assume greater porportions. Now, as these ships, the designs of which are presented herewith, are intended for very high speed, the element of surface-friction is no longer a matter of primary consideration, since the form of the vessel, which alone can make such a high speed possible, must here be of the first importance. It should also be observed, that the submerged stern, and the consequent great width of the lower hull towards the stern, greatly adds to the displacement, and proper investigation will show that the actual wetted surface of a ship of this design does not materially differ from that of an ordinary vessel of equal displacement, while, when the fineness of the lines or the sharpness of the entrance and run is taken into consideration, as it should be, and as is done in calculating the augmented surface according to Rankine, a ship upon this design has greatly the advantage.

It need hardly to be remarked that a sharp ship must have a greater immersed area for the displacement than one with fuller lines; and that a ship with twin screws must have a greater wetted surface than one of equal displacement with a single screw. Any fair comparison in this respect requires the vessels to be of about equal sharpness, and to have the same number of propellers. Let us, however, compare the ship of this design with the British dispatch-ship Iris, a twin screw vessel, and the fastest ship in the English Navy. In order to make such a comparison practicable we must first bring both vessels to equal displacement, and we will then assume that the Iris were enlarged to 13677 tons, as is the displacement of this ship, after which their immersed areas may be compared.

As stated in the paper by Mr. J. Wright to the Institution of Naval Architects, London, April 4, 1879, reprinted in the Navy Scientific Papers, No. 12, the Iris had, with 3290 tons displacement, a wetted surface of 18600 square feet. As, now, similar bodies are to each other as the cube of their respective dimensions, and their areas as the square of those dimensions, and letting d represent the displacement of the ship before the enlargement, D, the displacement after being enlarged, a, the area of the wetted surface before the enlargement, A, the area after being enlarged, l and L the respective dimensions:

$$d : D = l^3 : L^3; \qquad a : A = l^2 : L^2;$$

$$\sqrt[3]{d} : \sqrt[3]{D} = l : L; \qquad \sqrt{a} : \sqrt{A} = l : L, \text{ and } \qquad \sqrt{a} : \sqrt{A} = \sqrt[3]{d} : \sqrt[3]{D}$$

whence:

$$\sqrt{\frac{A}{a}} = \sqrt[3]{\frac{D}{d}}; \quad \frac{A}{a} = \left(\sqrt[3]{\frac{D}{d}}\right)^2; \quad \frac{A}{a} = \left(\frac{D}{d}\right)^{\frac{2}{3}}; \text{ and } A = a\left(\frac{D}{d}\right)^{\frac{2}{3}}.$$

Inserting the values in this equation, we obtain the immersed area of the enlarged ship:

$$A=\left(\frac{13677}{3290}\right)^{\frac{2}{3}};$$

$$\begin{array}{rl}
\text{Log. } 13677 = & 4.1359885 \\
\text{Log. } 3290 = & 3.5171959 \\
\hline
 & 0.6187926 \\
\tfrac{1}{3} = & 0.2062642 \\
\times\, 2 = & 0.4125284 \\
\text{Log. } 18600 = & 4.2695129 \\
\hline
\text{Log. A } = & 4.6820413 \\
\text{A} = & 48088 \text{ square feet.}
\end{array}$$

It thus appears that the Iris, if expanded to the displacement of this ship, would have 48088 square feet of wetted surface, while the ship of this design has only 44660; and it should be observed that this difference of over 3400 square feet in favor of this ship would be still greater if the Iris had equally fine lines as this vessel, or if the augmented surfaces of the two vessels were compared.

As before mentioned, any comparison of this nature between a twin screw ship and one with a single propeller must always be greatly to the disadvantage of the former, but we will, however, now compare this ship with the single screw steamer Charles V, before referred to; a vessel of very fine model and one of the sharpest merchant ships afloat. The displacement of the Charles V, as stated in Engineering of October 1, 1880, was on her trial trip 2478 tons and her augmented surface 15266 square feet:

$$\begin{array}{rl}
\text{Log. } 13677 = & 4.1359885 \\
\text{Log. } 2478 = & 3.3941013 \\
\hline
 & 0.7418872 \\
\tfrac{1}{3} = & 0.2472957 \\
\times\, 2 = & 0.4945914 \\
\text{Log. } 15266 = & 4.1837253 \\
\hline
\text{Log. A } = & 4.6783167 \\
\text{A} = & 47678 \text{ square feet.}
\end{array}$$

The augmented surface of this ship is 47233 square feet, being 445 square feet less. If the Charles V were a twin screw ship, the difference would, of course, have been much greater.

CONCLUSION.

In concluding this paper I would add that a ship upon my design, combining as it does the finest lines for high speed with greater carrying capacity than the ordinary vessel, also greater stability and steadiness in a sea-way, greatly increased handiness or quickness in answering the helm, and giving at the same time greater safety and comfort at sea, must be for mercantile purposes not only vastly superior in every respect to the common type of ship, but that it possesses, also, in higher degree than a vessel of the ordinary form, all the qualities desirable for a ship of war.

SCHEDULES AND CALCULATIONS.

Schedule of dimensions and other data relating to the smaller steamship.

Length of hull below water on the plane of greatest breadth........feet..	450.0
Greatest breadth...do ..	66.0
Length on load water-line...do...	444.0
Breadth on load water-line...do...	58.0
Draught of water at load water-line...do...	23.0
Length over all, on upper deck...do...	475.0
Breadth on upper deck at greatest transverse section (outside of frames)do...	62.0
Depth from top of upper deck beam to bottom plating...............do...	41.0
Height between the upper and second decks...........................do...	9.0
Height between the second and third decks...........................do...	9.0
Height between third and orlop decks...........................do...	8.0
Area of geatest immersed transverse section ....square feet..	1412.0
Coefficient of greatest immersed transverse section	0.9303
Area of load water-plane.................................square feet..	15255.0
Coefficient of load water-plane..	0.5924
Displacement to load water-line..............................cubic feet..	380836.0
Coefficient of fineness of displacement	0.5574
Horizontal distance of Center of Buoyancy from the submerged stern.feet..	225.326
Depth of Center of Buoyancy below the load water-plane............do...	11.446
Height of Meta Center above Center of Buoyancy...................do...	7.469
Height of Meta Center above Center of Gravity of the ship when fully equipped and loaded...feet..	3.458
Height of Meta Center above Center of Gravity of the ship at 14 feet draught of water, supposing her to have no cargo, coal, stores, water, or ballast, and no water in the boilers, but otherwise completely fitted and fully rigged ....feet..	5.060
Height of Meta Center above Center of Gravity of the ship at 9.6 feet draught of water, the hull being complete, with masts in and rigged, but empty, without engines and boilers...feet..	11.389
Surface of upper deck (outside of frames)....................square feet..	23641
Surface of second deck (outside of frames) ....do....	17884
Surface of third deck (outside of frames) ....do....	15256
Immersed surface to load water line..........................do....	38040
Angle of obliquity of load water-line at the bow..............................	6° 0′
Angle of obliquity at the stern	6° 30′
Mean angle of obliquity at entrance	7° 0′

The ship supposed to be built of steel, and to have engines developing 18000 indicated horse-power, being 9000 indicated horse-power on each propeller.

Schedule of dimensions and synopsis of calculations relating to the larger steam ship.

Length of hull below water on the plane of greatest breadth	feet..	490.0
Greatest breadth	do...	68.0
Length on load water-line	do...	480.0
Breadth on load water-line	do...	60.0
Draught of water at load water-line	do...	25.0
Length over all on upper deck	do...	496.0
Breadth on upper deck at greatest transverse section (outside of frames)	do...	64.0
Depth from top of upper deck beam to bottom plating	do...	44.0
Height between upper and second decks	do...	9.0
Height between second and third decks	do...	9.0
Height between third and orlop decks	do...	8.0
Area of greatest immersed transverse section	square feet..	1590.8
Coefficient of greatest immersed transverse section		0.9357
Area of load water-plane	square feet..	17230.8
Coefficient of load water-plane		0.5982
Displacement to load water-line	cubic feet..	478716.0
Coefficient of fineness of displacement		0.5747
Horizontal distance of Center of Buoyancy from the submerged stern	feet..	246.987
Depth of Center of Buoyancy below the load water-plane	do...	12.487
Height of Meta Center above Center of Buoyancy	do...	7.305
Height of Meta Center above Center of Gravity of the ship when fully equipped and loaded	feet..	3.616
Height of Meta Center above Center of Gravity of the ship at 15.5 feet draught of water, supposing her to have no cargo, coal, stores, water, or ballast, and no water in the boilers, but otherwise completely fitted and fully rigged	feet..	5.895
Height of Meta Center above Center of Gravity of the ship at 10.4 feet draught of water, the hull being complete, with masts in and rigged, but empty, without engines and boilers	feet..	13.211
Surface of upper deck (outside of frames)	square feet..	24451
Surface of second deck (outside of frames)	do...	20741
Surface of third deck (outside of frames)	do...	17574
Immersed surface to load water-line	do...	44660
Angle of obliquity of load water-line at the bow		6° 0′
Angle of obliquity at the stern		6° 30′
Mean angle of obliquity at entrance		7° 0′

Calculation of the displacement by the frames.

Area of frame No. 1= 23.0×1	23.0
No. 2= 93.9×4	375.6
No. 3=186.7×2	373.4
No. 4=289.5×4	1158.0
No. 5=394.8×2	789.6
No. 6=487.2×4	1948.8
No. 7=572.0×2	1144.0
No. 8=655.5×4	2622.0
No. 9=698.0×2	1396.0
No. 10=740.7×4	2962.8
No. 11=769.8×2	1539.6
No. 12=7-8.5×4	3154.0
No. 13=795.4×2	1590.8
No. 14=785.0×4	3140.0
No. 15=766.6×2	1533.2
No. 16=735.6×4	2942.4
No. 17=687.8×2	1375.6
No. 18=628.0×4	2512.0
No. 19=553.9×2	1107.8
No. 20=474.1×4	1896.4
No. 21=359.7×2	719.4
No. 22=255.3×4	1021.2
No. 23=157.6×2	315.2
No. 24= 67.0×4	268.0
No. 25= 7.5×1	7.5
	35916.3
	20
	3)718326.0
	239442.0
Part aft of frame No. 1	+214.0
Part fore of frame No. 25	+ 12.0
One-half displacement ... cubic feet	239668.0

Calculation of the displacement by the water-planes.

One-half water-plane	0 at 0 feet draught	=0000.0×1	00000.0
	$0\frac{1}{4}$ at 1	=7106.1×4	28424.4
	$0\frac{1}{2}$ at 2	=8358.4×2	16716.8
	$0\frac{3}{4}$ at 3	=9182.3×4	36729.2
	A at 4	=9824.1×1	9824.1
			91694.5

One-half cubic content of part 0—A=$\frac{1}{3}$ (interval between water-planes = 1) . 30564.8

One-half water-plane	A at 4 feet draught	= 9824.1×1	9824.1
	$A\frac{1}{2}$ at 6	=10678.0×4	42712.0
	B at 8	=11219.3×2	22438.6
	$B\frac{1}{2}$ at 10	=11249.1×4	44996.4
	C at 12	=10582.0×2	21164.0
	$C\frac{1}{2}$ at 14	=10052.0×4	40208.0
	D at 16	= 9614.8×2	19229.6
	$D\frac{1}{2}$ at 18	= 9264.2×4	37056.8
	E at 20	= 9008.6×2	18017.2
	$E\frac{1}{2}$ at 22	= 8809.8×4	35239.2
	F at 24	= 8703.5×1	8703.5
			299589.4

299589.4×2 (interval between the water-planes) 599178.8

	Cubic feet.
One-half cubic content of part A—F .... =$\frac{1}{3}$=	199726.3
One-half cubic content part 0—A	30564.8
One-half cubic content part A—F	199726.3
Part aft of water-planes	107.0
One-half displacement	239048.6
One-half displacement by frames	239668.0
Mean $\frac{1}{2}$ displacement	239358.3

Displacement=478716.6 cubic feet=13677.6 tons.

Calculation of the horizontal position of the Center of Buoyancy.

Frame No. 1. Function of frames=	23.1× 0	00000.0
No. 2.	375.6× 1	375.6
No. 3.	373.4× 2	746.8
No. 4.	1158.0× 3	3474.0
No. 5.	789.6× 4	3158.4
No. 6.	1948.8× 5	9744.0
No. 7.	1144.0× 6	6864.0
No. 8.	2622.0× 7	18354.0
No. 9.	1396.0× 8	11168.0
No. 10.	2962.8× 9	26665.2
No. 11.	1539.6×10	15396.0
No. 12.	3154.0×11	34694.0
No. 13.	1590.8×12	19089.6
No. 14.	3140.0×13	40820.0
No. 15.	1533.2×14	21464.8
No. 16.	2942.4×15	44136.0
No. 17.	1375.6×16	22009.6
No. 18.	2512.0×17	42704.0
No. 19.	1107.8×18	19940.4
No. 20.	1896.4×19	36031.6
No. 21.	719.4×20	14388.0
No. 22.	1021.2×21	21445.2
No. 23.	315.2×22	6934.4
No. 24.	268.0×23	6164.0
No. 25.	7.5×24	180.0
	35916.3	425947.6

$$\frac{425947.6}{35916.3}=11.8595$$

Center of part frame 1—25 distant from 1 = 20×11.8595 = 237.19 feet.
Center of part frame 1—25 distant from submerged stern = 247.19 feet.

Cubic content of part 1—25=	239442.0×247.19 = moment	59187668
Cubic content of part aft frame 1	214.0× 6.0	1284
Cubic content of part fore frame 25	12.0×492.0	5904
	239668.0	59194856

$$\text{Center of Buoyancy distant from submerged stern} = \frac{59194856}{239668} = 246.987 \text{ feet.}$$

Calculation of the vertical position of the Center of Buoyancy.

Function of water-plane 0 at 0 feet draught =	00000.0×0	....	00000.0
0¼ at 1	28424.4×1	....	28424.4
0½ at 2	16716.8×2	....	33433.6
0¾ at 3	36729.2×3	....	110187.6
A at 4	9824.1×4	....	39296.4
	91694.5		211342.0

Center of part 0—A distant from $0 = \frac{211342.0}{91694.5} = 2.305$ feet.

Center of part 0—A distant from load water-plane = 22.695 feet.

Function of water-plane A at 4 feet draught =	9824.1× 0	....	00000.0
A½ at 6................	42712.0× 1	....	42712.0
B at 8................	22438.6× 2	....	44877.2
B½ at 10................	44996.4× 3	....	134989.2
C at 12................	21164.0× 4	....	84656.0
C½ at 14................	40208.0× 5	....	201040.0
D at 16................	19229.6× 6	....	115377.6
D½ at 18................	37056.8× 7	....	259397.6
E at 20................	18017.2× 8	....	144137.6
E½ at 22................	35239.2× 9	....	317152.8
F at 24................	8703.5×10	....	87035.0
	299589.4		1431375.0

Center of part A—F distant from $A = \frac{2 \times 1431375.0}{299589.4} = 9.556$ feet.

Center of part A—F distant from load water-plane = 11.444 feet.

Cubic content of part water-plane 0—A=	30564.8×22.695	= mom. =.	693668
Cubic content of part water-plane A—F	199726.3×11.444	....	2285668
Cubic content of part water-plane F—l.w.pl.	8650.5× 0.5	....	4325
Cubic content of part aft of water-planes	107.0×14.0	....	1498
	239048.6		2985159

Center of Buoyancy distant from load water-plane $= \frac{2985159}{239048} = 12.487$ feet.

Calculation of the height of Meta Center above the Center of Buoyancy.

Frame No. 1	Ord. = 0.0	Cube of ord. = 0000.0×1	0000.0
No. 2	2.1	9.2×4	36.8
No. 3	5.2	140.6×2	281.2
No. 4	8.9	705.0×4	2820.0
No. 5	12.7	2048.4×2	4096.8
No. 6	16.6	4574.3×4	18297.2
No. 7	20.2	8242.2×4	16484.8
No. 8	23.3	12649.3×4	50597.2
No. 9	26.0	17576.0×2	35152.0
No. 10	27.8	21484.9×4	85939.6
No. 11	29.0	24389.0×2	48778.0
No. 12	29.7	26198.0×4	104792.0
No. 13	30.0	27000.0×2	54000.0
No. 14	29.6	25934.3×4	10373.2
No. 15	28.9	24137.6×2	48275.2
No. 16	27.6	21024.6×4	84098.4
No. 17	25.8	17173.5×2	34342.0
No. 18	23.4	12812.9×4	51251.6
No. 19	20.4	8489.7×2	16979.4
No. 20	16.9	4826.8×4	19307.2
No. 21	13.0	2197.0×2	4394.0
No. 22	8.9	705.0×4	2820.0
No. 23	5.3	148.9×2	297 8
No. 24	2.4	13.8×4	55.2
No. 25	0.4	0.1×1	0.1
			786838.7
			20
			3)15736774.0
			5245591.3

Moment of inertia of load water-plane .... $\frac{2}{3}$ = 3497060.9

(Displacement = 478716 cubic feet.)

$$\text{Meta Center above Center of Buoyancy} = \frac{3497060.9}{478716.6} = 7.305 \text{ feet.}$$

The ship is supposed to be constructed of steel, with the greatest strength and solidity throughout, and with that object in view many of its component parts are assumed exceptionally heavy. Longitudinal bulkheads of 1 inch thickness run the whole length of the vessel, extending up to the second deck, or 9 feet above the load water-line, and which, in addition to numerous transverse bulkheads or water-tight compartments, will keep the ship afloat under all probable contingencies, or make her practically unsinkable.

Space not permitting to insert the computations at length, regarding the center of gravity of the ship, the results only are given, as follows:

Calculation of the vertical height of the Center of Gravity of the ship and the Meta Centric height on 25 feet draught of water, the ship having then a full complement of passengers, 3200 tons coal, and 611 tons express cargo.

	Weight.	Distance of Center of Gravity from load water-line.	Moments. Below load water-line.	Moments. Above load water-line.
	Tons.		*Foot-tons.*	*Foot-tons.*
Ship's hull, with decks	5171.0	5.7	29474.0	....
Masts, sails, and rigging	80.0	70.0	....	5600.0
On upper deck: Anchors and cables, deck-houses, winches, boats, galleys, steering apparatus, &c	171.8	23.0	....	3951.4
On second deck: Cabin fittings, &c	123.0	13.8	....	1697.4
On third deck: Cabin fittings, &c	130.2	5.0	....	651.0
On orlop deck: Fittings for third-class passengers, &c	30.0	4.2	126.0	....
Chains and cables and hawsers, besides those on upper deck	40.0	17.0	680.0	....
Watertanks and water	120.0	16.7	2004.0	....
Stores, provisions, &c	100.0	....	....	....
Engines, boilers and water, funnels and ventilators	3700.0	14.3	52910.0	....
Coal in bunkers	2400.0	12.7	30480.0	....
Coal in the hold	800.0	14.8	11840.0	....
Crew, passengers, and luggage	200.0	3.6	....	720.0
Express cargo	611.0	8.9	5437.9	....
	13677.0	....	132951.9	12619.8
			12619.8	
			120332.1	

		Feet.
Center of Gravity of the ship below load water-line	$\frac{120332.1}{13677} =$	8.798
Center of Buoyancy below load water-line		12.487
Center of Gravity above Center of Buoyancy		3.689
Meta Center above Center of Buoyancy		7.305
Meta Center above Center of Gravity of the ship		3.616

Calculation of the Meta Centric height at 15.5 *feet draught of water, the ship having no cargo, coal, stores, water, or ballast, and no water in the boilers, but otherwise completely fitted and fully rigged.*

Displacement at 25 feet draught	13677 tons		mom.=	120332 foot-tons.
Cargo	611 tons		mom.= 2438	
Coal	3200 tons		mom. 42320	
Stores	100 tons		mom.	
Water and tanks	120 tons		mom. 2004	
Water in boilers	700 tons		mom. 10150	
Crew, pass., and lugg.	200 tons	720		
	4931	4931	56912	
			720	
			56192	56192
Displ. at 15.5 feet = 306110 cub. feet = 8746 tons			mom=	64120

Center of Gravity below load water-line, at 25 feet draught, $=\frac{64120}{8746}=7.333$ feet.

Water plane A	= 9824.0×1=	9824.0×0	00000
A½	10678.0×4	42712.0×1	42712.0
B	11219.3×2	22438.6×2	44877.2
B½	11249.1×4	44996.4×3	134989.2
C	10582.0×2	21164.0×4	84656.0
C½	10052.0×4	40208.0×5	201040.0
D	9614.8×1	9614.8×6	57688.8
		190957.8	565963.2
		2	
		381915.6	
Cubic contents A — D = ⅓ =		127305.2	

Center of A—D distant from A$=\frac{2\times 565963.2}{190957.8}=5.927$ feet.

Center distant from load water-line=21—5.927=15.073.

Cubic contents	A—D=127305.2	mom.=	1918871.3
Cubic contents	15.5—D= 4922.0	mom.	45568.4
Cubic contents	15.5—A=122383.2		1873302.9
Cubic contents	O—A= 30564.8		693668.1
Cubic contents aft of water-plane	107.0		1498.0
One-half displacement to	15.5=153055.0		2568469.0

Center of Buoyancy below load water-line, at 25 feet draught$=\frac{2568469}{153055}=16.781$ feet.

Frame No. 1.	Ord. 0.0	Cube of ord. 0.0×1	000000.0
No. 2	2.6	17.5×4	70.0
No. 3	6.8	314.4×2	628.8
No. 4	11.2	1404.9×4	5619.6
No. 5	15.5	3723.8×2	7447.6
No. 6	19.7	7645.4×4	30581.6
No. 7	23.3	12649.3×2	25298.6
No. 8	26.3	18191.4×4	72765.6
No. 9	28.6	23393.6×2	46786.2
No. 10	30.0	27000.0×4	108000.0
No. 11	31.5	31255.8×2	62511.6
No. 12	32.4	34012.2×4	136048.8
No. 13	32.5	34328.1×2	68656.2
No. 14	32.3	33698.2×4	134792.8
No. 15	31.3	30664.3×2	61328.6
No. 16	30.0	27000.0×4	108000.0
No. 17	28.2	22425.7×2	44851.4
No. 18	25.7	19974.6×4	79898.4
No. 19	22.6	11543.2×2	23086.4
No. 20	19.1	6967.8×4	27871.2
No. 21	15.0	3375.0×2	6750.0
No. 22	10.8	1259.7×4	5038.8
No. 23	6.7	300.7×2	601.4
No. 24	3.2	32.7×4	130.8
No. 25	0.3	0.1×1	0.1
			1056764.5
			20
			3)21135290.0
			7045096.7

Moment of inertia of water-plane .... $=\frac{2}{3}=4696731.1$

$$\text{Meta Center above Center of Buoyancy}=\frac{4696731}{306110}=15.343 \text{ feet.}$$

Meta Center above Center of Buoyancy	15.343 feet.
Meta Center below load water-line	1.438
Center of Gravity below load water-line	7.333
Meta Center above Center of Gravity	5.895 feet

Calculation of the Meta Centric height at 10.4 *feet draught of water, the ship being empty and without engines and boilers but fully rigged.*

Displacement at 25 feet draught		13677 tons			mom.=120332 foot-tons
Cargo	611 tons	mom.=	2438		
Coal	3200 tons	mom.	42320		
Stores	100 tons	mom.			
Water and tanks	120 tons	mom.	2004		
Engines and boilers	3700 tons	mom.	52910		
Crew, pass. and lugg.	200 tons	mom.		720	
	7931	7931	99672		
			720		
			98952		98952
Displ. at 10.4 feet=201110 cubic feet=5746 tons					mom.= 21380

Center of Gravity below load water-line, 25 feet draught $=\frac{21380}{5746}=3.720$ feet.

Water-plane A =	9824.0×1=	9824.0×0	00000.0
A½	10678.0×4	42712.0×1	42712.0
B	11219.3×2	22438.6×2	44877.2
B½	11249.1×4	44996.4×3	134989.2
C	10582.0×1	10582.0×4	42328.0
		130553.0	264906.4
		2	
		261106.0	
Cubic contents A—C = ⅓ =		87035.3	

Center of A—C, distant from A $=\frac{2\times264906.4}{130553.0}=4.058$ feet.

Center distant from load water-line =16.942 feet.

Cubic contents	A—C=87035.3	mom.=1474552.0
Cubic contents	10.4—C=17152.1×13.77	236186.4
Cubic contents	10.4—A=69883.2	mom.=1238365.6
Cubic contents	0—A=30564.8	693668.1
Cubic contents aft of water-plane	107.0	1498.0
One-half displacement to	10.4=100555.0	mom.=1933531.7

Center of Buoyancy below load water-line, 25 feet draught $=\frac{1933531.7}{100555.0}=19.226$ feet.

Frame No. 1	Ord. 0.0	Cube of ord. 0.0×1	00000.0
No. 2	13.0	2197.0×4	8788.0
No. 3	14.8	3241.7×2	6483.4
No. 4	18.4	6229.5×4	24918.0
No. 5	21.5	9938.3×2	19876.6
No. 6	24.2	14712.4×4	58849.6
No. 7	26.5	18609.6×2	37219.2
No. 8	28.5	23149.1×4	92596.4
No. 9	30.4	28094.4×2	56188.8
No. 10	31.8	32157.4×4	128629.6
No. 11	32.9	35611.3×2	71222.6
No. 12	33.6	37933.0×4	151732.0
No. 13	33.9	38958.2×2	77916.4
No. 14	33.6	37933.0×4	151732.0
No. 15	32.7	34965.7×2	69931.4
No. 16	31.6	31554.4×4	126217.6
No. 17	29.7	26198.0×2	52396.0
No. 18	27.4	20570.8×4	82283.2
No. 19	24.3	14348.9×2	28697.8
No. 20	20.7	8869.7×4	35478.8
No. 21	16.7	4657.4×2	9314.8
No. 22	12.6	2000.3×4	8001.2
No. 23	8.4	592.7×2	1185.4
No. 24	4.0	64.0×4	256.0
No. 25	0.3	0.1×1	0.1
			1299914.9
			20
			3)25998298.0
			8666099.3
Moment of inertia			$=\frac{2}{3}=$5777399.5

$$\text{Meta Center above Center of Buoyancy} = \frac{5777399}{201110} = 28.727 \text{ feet.}$$

Meta Center above Center of Buoyancy	28.727
Meta Center above load water-line	9.501
Center of Gravity below load water-line	3.710
Meta Center above Center of Gravity	13.211 feet

1

SOME REMARKS UPON AND EXTRACTS FROM BEAUFOY'S NAUTICAL EXPERIMENTS.

The great problem of determining the most suitable form of vessel for dividing the water with the greatest facility, or, in other words, to discover and design the shape of the body that would meet with the least possible resistance when impelled through the water by the force of sails or machinery, has, during all ages, engaged the attention of scientific and practical men among the sea-faring nations of the globe. If, however, the question should be put whether there has been any real progress made within the last thousand years toward the solution of the problem, the answer would be doubtful; or, rather, it would hardly be safe to reply in the affirmative. To the great majority of people this statement may possibly appear highly improbable, accustomed as we have been made, in this age of wonderful discoveries and inventions, to look for improvement as a matter of course in every branch of human pursuit; but it is nevertheless based upon such facts as to make it perfectly tenable. The ships of the present day surpass those of the ancients in size, and, as a natural consequence, also in endurance and power to defy the gales and seas of the ocean; but mere increase of size does not by any means also imply improvement in shape. Besides, it is well known that in ancient times, long before the Christian era, there were ships built which in point of magnitude might be compared with even the greatest vessels of the present day.

The accounts that have reached us of those ancient vessels of the Phœnicians, the Egyptians, the Sicilians, the Greeks, and the Romans, are, however, altogether too meager to enable us to form anything but an approximate idea of the form of the ship's hull and the proportion of its dimensions. But it may be assumed with considerable probability that the proportions did not differ very much from those of the sailing ship of the present age.

The Vikings of the Scandinavian peoples, who for centuries were a terror to all the European nations bordering on the sea-coasts, who conquered England and erected independent powers in France and Italy, possessed, no doubt, the fleetest and best constructed vessels then existing, enabling them to grasp and for a long time retain the mastery of the seas. It was the custom, when any one of those sea kings died, to inter him together with his favorite ship, which was dragged on shore and a huge mound of earth raised around and over it. There are many such to be found about the numerous inlets and fjords of the Scandinavian peninsula, particularly Norway, but explorations generally proved, as expected, that the many centuries had done their work, leaving the decayed *débris* of the craft only, thus making it impossible to form but a crude idea of the form of the vessel. Four years ago, however, one of these explorations in Norway proved more successful. Owing to some exceptional circumstances it happened that the wood had been preserved in a surprising degree, and the old sea king's "drake" (as the Viking ships were termed) was found nearly intact and resurrected from its sleep of a thousand years. The scientific papers and periodicals of the time had descriptions of the vessel, which now has its place in the University of Christiania. It is not intended to repeat that description here, but it may be mentioned that the dimensions are: length, 74; greatest beam, 16½, and draught of water probably about 8 feet. It will be seen that the proportion of

these dimensions do not materially differ from those of the best sailing ships of the present day; but what strikes the beholder with surprise and admiration is the beautiful form of its hull. Its lines are admirable for speed, carrying capacity, and stability, and will compare favorably in these respects with the best designed ship of this day.

During the latter part of the last century and the beginning of the present one, several of the most profound mathematicians the world has produced appeared to direct their genius to the problem of determining the law governing the motion of fluids and the resistance to bodies moving through them.

D'Alembert, De Condorcet, Bossut, and De Borda, in France, and Euler, in Germany, devoted much labor to the subject, and the celebrated Chapman, in Sweden, the ablest naval architect of that period, carried out a series of experiments by order of the government.

The effect of these efforts soon showed itself, for France and Sweden produced the best and fastest ships, and this circumstance, which was too plainly seen to be ignored, soon roused, as might be expected, the ambition of the English not to be behind in acquiring knowledge upon a subject, which was apparently of more importance to them than to any other nation.

In the preface to Colonel Beaufoy's works it is said:

In a maritime and commercial country like Great Britain it is evident that the most effectual management of its naval strength must constitute an object of the first magnitude and importance. As the fleets of a kingdom so circumstanced are the foundation of its consequence among neighboring nations and the defense of its commerce in time of war, it must follow as an undeniable truth that the safety, the prosperity, and even the existence of its commerce must very much depend on the excellent construction of the ships in its service.

It is but too well known to all who have any skill in naval architecture that the theory is not so well understood as it deserves; and the Swedes and French actually surpassing the English in this most important art; the French having derived many advantages from this superiority in time of war.

Now, in a country so fertile as Great Britain in men of genius, where the most skillful and industrious workmen are always to be found, and the best materials to be procured, nothing but public encouragement and a firm union of theoretical and practical ability can be wanting to produce the desired remedy, and to enable England to excel not only her neighbors, the French, but all other maritime countries, in constructing ships of war and merchantmen.

For these reasons, and in order most effectually to accomplish so desirable a purpose, it was proposed to establish "A Society for the Improvement of Naval Architecture," the grand object of which should be to improve and strengthen the Royal Navy of Great Britain and her shipping in general for the benefit of the public and merchant service.

A meeting, in consequence of public advertisement, was accordingly held on 14th April, 1791, to take into consideration the expediency of instituting "A Society for the Improvement of Naval Architecture." It was attended by a numerous company of noblemen and gentlemen, when it was unanimously agreed:

That the theory and art of shipbuilding, being objects of the first magnitude and importance to these kingdoms, are not so well understood in this country as matters of so much consequence deserve, and a remedy for this radical deficiency merited the attention of every well-wisher to the true interests of Great Britain.

That the most effectual remedy for this deficiency would be to concentrate the theoretical and practical wisdom of this country by the institution of a society for the improvement of naval architecture.

That such a society is instituted under the direction of a president, vice-presidents, and other officers, and that his royal highness, the Duke of Clarence, be requested to accept the office of president, and to lay the plan of it before His Majesty.

The society resolved, by the assistance of their own members and other gentlemen properly qualified, to make a series of experiments on the resistance of water upon a much more extensive scale than any which had yet been made in this or any other country.

The Greenland dock was fixed upon as the largest and most convenient piece of still water for the purpose near London.

The society, which counted among its members the most scientific men in Great Britain, unanimously chose Colonel Beaufoy to conduct the

experiments. And this trust he fulfilled with greatest possible zeal, never absenting himself for a single day when the experiments were made during all the years that they lasted.

Colonel Beaufoy was eminently qualified for this task; a scientist of high attainments and enthusiastically devoted to the work entrusted to him, with the nature of which he was well acquainted, having previously made elaborate experiments with a pendulum swinging in water, with small bodies of different shape attached, for the purpose of finding their comparative resistance.

These experiments are of great scientific interest, and the most important conclusion drawn from them was that the resistance was least when the greatest breadth of the moving body was placed at a distance of two-fifths of the length from the fore end.

As, however, the bodies experimented upon with the pendulum were very small, and the line of motion arched instead of straight, and at different depths of water, the practical value of these experiments is necessarily lessened, and the object of the present paper is, therefore, to speak more particularly of the experiments made in Greenland dock.

These experiments were commenced in 1793, and continued during the following six years, until 1798; and over ten years more were required to conclude the necessary calculations and prepare the work for publication. It then became known that similar experiments had been made in Sweden by Lagerhjelm, Forselles, and Kallstenius, who sent copies of the volume containing their researches to Colonel Beaufoy. It was then determined to have the Swedish work translated into English, and published together with Colonel Beaufoy's experiments, but obstacles came in the way causing yet further delay in the publication. Colonel Beaufoy died in 1827, bequeathing his manuscripts to his son, who determined to publish them in a separate volume, which was done at last in 1834. Only a limited number of copies were printed and presented to foreign governments and learned societies. The work being thus very rare, and accessible to the public only in a few public libraries, accounts for its being known only to a limited number of readers. The practical deductions that may be drawn from these experiments are of so great importance that if they had been more generally known and digested, there is every probability that naval architecture would have profited far more by them than is now the case.

There were between nine and ten thousand experiments made during those years. In that particular branch of hydrostatics they stand without a parallel, not only as to extent but also as to accuracy, for they were executed with the utmost attention to every detail that could have any influence on the result, which was corrected accordingly. The most eminent mathematicians in the country, among whom may be mentioned the celebrated Dr. Hutton, assisted in planning the mode of conducting the experiments, and the latter in particular revised the mode of calculations. It should also be observed that the experiments were made with bodies of much larger size than commonly used in similar investigations, and the velocities reached were also considerably greater, both circumstances of great importance in obtaining reliable practical results.

The bodies were drawn through the water by a rope running through a series of blocks acted upon by weights, the number of which blocks varied for the different velocities. By a simple device, the velocity of the body for each second was accurately measured within the hundredth part of a foot by a pendulum causing a pencil mark to be made on a sliding scale moving according to the velocity. The weight would naturally cause an accelerating motion until the body had attained the

velocity where the resistance of the water would be equal to the weight, after which the velocity would be uniform. An additional weight, applied at the commencement, helped to shorten the time of acceleration, dropping off when the uniform velocity was attained.

The bodies varied in length from 4 to 44 feet, and in breadth and depth from 1 to 7.336 feet. The motive weights varied from 2 to 800 pounds, and the accelerating weight, added to get up more quickly to the uniform speed, weighed sometimes over 8000 pounds. A velocity of about 13 feet per second, corresponding to 8 knots per hour, was thus reached, and in some instances as high as 20 feet per second. Several runs were made with the same weight and the mean taken, but so perfect was the arrangement that the difference between the several runs was generally but trifling. From the results obtained, the resistance was calculated for every foot velocity up to 13.257 feet per second, being exactly 8 knots per hour.

The following example will show the method suggested by Dr. Hutton and used in performing the calculations: The body was 28.309 feet long, the middle part being a parallelopipedon and the ends vertical wedges with the angle of obliquity $=9^{\circ} 35' 40''$. The motive weights were, 4 pounds 3 ounces, 8 pounds 6 ounces, 16 pounds 12 ounces, 33 pounds 8 ounces, and 67 pounds. The velocities obtained, after the corrections for friction of the blocks, thickness of the lines, &c., were, respectively, 2.8875, 4.0250, 5.5083, 7.0500, and 9.4000 feet per second; or,

	Motive weights.				
	4 lbs., 3 oz.	8–6	16–12	33–8	67–0
Velocity in feet per second	2.8875	4.0250	5.5083	7.0500	9.4000

The values in the first two columns are then compared with each other in order to find the law of resistance for these two sets. The values in the first and third, first and fourth, and first and fifth columns are similarly treated; and then the second and third, second and fourth, second and fifth, third and fourth, and so on until the last two columns. Examining now the first and second columns, it is seen that the motive weights are not analogous to the speed, or

$$\frac{8 \text{ pounds } 6 \text{ ounces}}{4 \text{ pounds } 3 \text{ ounces}} = \frac{2}{1} \text{ is not equal to } \frac{4.0250}{2.8875}.$$

But the last quantity may be raised to a certain power, which shall make it equal to 2. Calling the exponent of that power m, we have:

$$2 = \left(\frac{4.0250}{2.8875}\right)^m,$$

and

$$\text{Log. } 2 = m \times \text{Log.}\left(\frac{4.0250}{2.8875}\right);$$

whence:

$$m = \frac{\text{Log. } 2}{\text{Log.}\left(\frac{4.0250}{2.8875}\right)}.$$

$$\text{Log. } 4.0250 = 0.6047659$$
$$\text{Log. } 2.8875 = 0.4605218$$
$$\text{Log.}\left(\frac{4.0250}{2.8875}\right) = 0.1442441; \text{ Log. } 2 = 0.3010300;$$

$$m = \frac{0.3010300}{0.1442441} = 2.0870.$$

In this way all the sets are treated, and the exponents will then be found as follows:

First and second set as above	2.0870
First and third set	2.1464
First and fourth set	2.3295
First and fifth set	2.3489
Second and third set	2.2093
Second and fourth set	2.4733
Second and fifth set	2.4516
Third and fourth set	2.8089
Third and fifth set	2.5939
Fourth and fifth set	2.4094

The mean of all these exponents is 2.3858, and this index of power will nearest express the law of resistance. By inspecting the columns it will be seen that the exponent obtained from the data in the fourth and fifth columns comes nearest to it, and, using the values in one of these columns, the different speeds corresponding to the motive weights in the other columns are calculated according to the ratio as expressed by the exponent 2.3885.

The corrected velocities for every motive weight used in the experiment thus calculated is called the "Huttonian Correction, or Regular Series." The resistance is then calculated for every velocity from 1 to 12.527 feet per second, the last being equal to 8 knots per hour.

The friction of the water was determined by ascertaining the resistance of two bodies having exactly similar ends and middle body, differing only in length, as in that case any difference in resistance must be due to the friction alone. And that difference, divided by the excess of surface in square feet of the longer body, gave the friction per square foot for that particular speed. The bodies were planed smooth and painted. Such experiments to determine the friction were made with bodies of different shape at the surface of the water, and submerged to a depth of six feet. The mean result, accepted by Colonel Beaufoy as the friction for that kind of surface, was as follows:

Velocity in feet per second.	Friction per square foot.	Index of power.
1	0.0037	....
2	0.0143	1.9802
3	0.0313	1.9575
4	0.0546	1.9394
5	0.0843	1.9241
6	0.1199	1.9088
7	0.1615	1.8942
8	0.2091	1.8822
9	0.2624	1.8697
10	0.3215	1.8563
11	0.3863	1.8412
12	0.4568	1.8391
12.527	0.5754	1.8167

It will be seen that the index of power decreases; and it should be observed that the law of friction resistance as deduced by Colonel Beaufoy closely agrees with the later investigations of Mr. Froude.

After deducting the friction from the total resistance of the body experimented with, there remained the actual resistance due to both ends. This resistance Colonel Beaufoy divided into "plus" and "minus" pressure; the former being the resistance due to the head and the latter to the stern end. The difference between these two kinds of resistance

was determined in the following manner: Two bodies were tried, having exactly similar heads and middle bodies, but different stern ends. The middle body consisted of a parallelopipedon and the head end of a vertical wedge, the angle of obliquity of which was 9° 35′ 40″. The stern end of one body was exactly like the head end, but in the other body the wedge was longer, the angle of obliquity being only 6° 22′ 45″:

FIRST BODY.

	Pounds.
Resistance at the speed of 13.527 feet per second, or 8 knots	41.10
From which deduct friction	5.70
Plus and minus pressure	35.40

SECOND BODY.

	Pounds.
Resistance at 13.527 feet per second, or 8 knots	40.63
From which deduct friction	6.58
Remains plus and minus pressure	34.05

The difference between the plus and minus pressure of the two bodies was thus =1.35 pounds, but as the pressure against the head ends must be equal for both bodies, and as the friction is wholly taken away this difference must be due to the minus pressure only; and as this difference was very small compared with the great difference in length of the stern ends, it was inferred that the longer and sharper stern end, having an angle of obliquity of 6° 22′ 45″, had no minus pressure, or, if any, that it was so small as to be of no moment.

Similar experiments were made with pairs of other bodies, having, as before mentioned, the middle bodies and head ends alike, but the stern ends similar to those in the previous example. Thus another set gave:

	Pounds.
Resistance of the first body	46.72
Deduct friction	4.45
Plus and minus pressure	42.27
Resistance of the second body	46.54
Deduct friction	5.33
Plus and minus pressure	41.21
Difference of the plus and minus pressure	1.06

Another set:

Resistance of the first body	154.81
Deduct friction	4.00
Plus and minus pressure	150.81
Resistance of the second body	154.54
Deduct friction	4.87
Plus and minus pressure	149.67
Difference of the plus and minus pressure	1.14

The difference of the "minus pressure" being thus 1.35, 1.06, and 1.14 pounds, or very nearly equal, shows the accuracy of the different experiments.

The experiments just mentioned were all made with the bodies submerged 6 feet below the surface; and from the results obtained Colonel Beaufoy deduced the law of resistance, as follows:

Feet per second.	Index of power.	
	Plus pressure.*	Minus pressure.
2	1.9987	2.0297
3	1.9822	2.0553
4	1.9688	2.0781
5	1.9572	2.0306
6	1.9486	2.1812
7	1.9392	2.1148
8	1.9308	2.0553
9	1.9236	2.1336
10	1.9165	2.0076
11	1.9092	2.2654
12	1.9015	1.9839
13.527	1.8941	2.1432

*Mean decrease of index of power=0.0095.

When the wedges in the stern ends were less sharp the minus pressure, as might be expected, rapidly increased. Thus a body with head and middle body similar to that in the first experiment here mentioned, but having a shorter stern wedge, the angle of obliquity being=19° 28′ 16″, gave the following result:

	Pounds.
Whole resistance	49.61
Deduct friction	4.83
Plus and minus pressure	44.78
Plus pressure as before obtained	34.34
Remains minus pressure	10.44

Another similar body having a still shorter stern wedge, the angle of obliquity being 30° 0′ 0″, gave:

	Pounds.
Whole resistance	70.72
Deduct friction	4.50
Plus and minus pressure	66.22
Plus pressure as before	34.34
Minus pressure	31.88

It is evident that the "minus pressure" is the same as the eddy resistance caused by the want of a "clean run." The experiments show that there was little or no minus pressure when the angle of obliquity of the stern wedge was 6° 22′ 45″, while when the angle of obliquity was 9° 35′ 40″ there was a small minus pressure of 1.6 pounds. The minus pressure, or stern resistance, was consequently, in that case, equal to 2.4 per cent of the whole resistance (less friction); but when the angle of obliquity of the stern wedge was 19° 28′ 16″, the minus pressure was 10.44 pounds or 23.3 per cent. of the whole resistance; and when the angle of obliquity at the stern was 30° the minus pressure, or eddy resistance of the stern, increased to 31.88 pounds or 48.1 per cent. of the whole resistance.

These experiments show the importance of having a "clean run" when speed is an object.

As before mentioned, the experiments in the years 1793, 1794, and

1795 were made with bodies at the surface of the water. Those made during the years 1796, 1797, and 1798 were all with the bodies submerged 6 feet below the surface. A few examples will now be given in order to compare the results obtained from the experiments at the surface with those of the same bodies submerged to a depth of 6 feet.

No. 1.—*At the surface.*

(Beaufoy, p. 81.)

The body was a parallelopipedon of 21.099 feet in length and 1.219 feet in width and in depth, the section being = 1.4859 square feet. The body was even with the water, the immersed surface being 77.16 square feet:

	Pounds.
Whole resistance at 13.527 feet per second (equal to 8 knots)	332.47
Friction on 77.16 square feet (@ 0.5754 pounds per foot)	44.39
Plus and minus pressure	288.08

The same body submerged.

(Beaufoy, p. 187.)

	Pounds.
Whole resistance at 13.527 feet per second	312.53
Friction on 102.88 square feet	59.29
Plus and minus pressure	253.24

The body when submerged had, consequently, 34.84 pounds less resistance than at the surface. If friction is assumed for the whole surface of the first body, which may be fair, as the water would flow over part of the upper surface during the progress, the difference would still be 19.94 pounds less resistance for the submerged body. The difference in the former case amounts to 10.4 and in the latter case to 6 per cent. of the whole resistance (332.47 pounds).

No. 2.—*At the surface.* (*Speed*, 8 *knots.*)

(Beaufoy, p. 129.)

The middle part of the body was a parallelopipedon, having a vertical wedge at the stern end, with the angle of obliquity = 9° 35′ 40″:

	Pounds.
Whole resistance	308.61
Friction on bottom and two sides=81.55 square feet	46.92
Plus and minus pressure	261.69

The same body submerged. (*Speed*, 8 *knots.*)

(Beaufoy, p. 192.)

	Pounds.
Whole resistance	278.81
Friction on 107.27 square feet	61.72
Plus and minus pressure	207.09

Difference, less resistance, for the submerged body, 54.60 pounds, being 17.7 per cent. of the whole resistance.

Assuming the friction for the body at the surface on the upper side also, or equal to that of the submerged body, the difference or less resistance for the submerged body is 29.80 pounds, which is 9.7 per cent. of the whole resistance, (308.61 pounds).

No. 3.—*At the surface.* (*Speed,* 8 *knots.*)

(Beaufoy, p. 139.)

The middle part of the body consisted of a parallelopipedon (same as in Example No. 1), having vertical wedges at the ends, both exactly alike, the angle of obliquity being 9° 35′ 40″:

	Pounds.
Whole resistance	129.20
Friction on 99.38 square feet	57.18
Plus and minus pressure	72.02

The same body submerged. (*Speed,* 8 *knots.*)

(Beaufoy, p. 209.)

	Pounds.
Whole resistance	121.00
Friction on 129.49 square feet	74.51
Plus and minus pressure	46.49

Difference, less resistance for the submerged body, 25.53 pounds, being 18.1 per cent. of the whole resistance.

Assuming the friction on the top side also of the body at the surface, the difference is still 8.20 pounds less resistance for the submerged body, or 9.3 per cent. of the whole resistance.

These examples might be multiplied, and they prove conclusively the truth of the important fact that the resistance to a body or vessel is considerably greater at the surface of the water than below it.

This circumstance did not escape Colonel Beaufoy and his assistants; but it would seem that they did not appreciate its very great importance.

In the preface to Colonel Beaufoy's works, Chapter IV, the subject is touched upon in these words:

"By comparing the resistance of the bodies near the surface with those having similar head and stern ends, immersed to the mean depth of six feet, it is observed that, in all cases (friction excepted), those at the surface experienced more retardation in dividing the fluid than the others immersed lower down. This will appear by the following examples." * * *

But an examination of the experiments does also bring to light another highly important circumstance, namely:

The resistance at the surface of the water increases in a higher ratio than as the square of the velocity, while the ratio for the submerged bodies is less than as the square of the velocity.

And again:

The ratio of the resistance at the surface increases, while below the surface it decreases.

Experiments with bodies having horizontal wedges at the ends, instead of vertical ones, thus dividing the water horizontally, showed less

resistance for those with the horizontal wedges, the angle of incident being in both cases the same. Regarding this fact, Colonel Beaufoy says:

"A very singular circumstance appears by comparing the experiments made (see pages 139 and 155). The water in both cases impinges on the same angle of incidence and the circumstances vary only in one particular. In the latter case, the displaced water is forced under the bottom of the figure; but it is very remarkable that the latter body should have so much less resistance than the former; nor is it less curious that as an after body, or stern end, it has a decided advantage over the other. And by inspecting the different experiments a constructor of vessels must be convinced of the vast advantage the oblique stern has over the upright one; and if to this superiority be joined the great benefit that accrues in a head sea when turning to windward, it seems hardly possible that ships should not be built on this plan in future."

The following experiments will illustrate this:

No. 4.—*At the surface.* (*Speed*, 8 *knots.*)

The middle part of the body was similar to that of the body in example No. 3 (p. 139), but the head and stern ends consisted of horizontal wedges instead of vertical ones, as in example No. 3. The angle of incidence was the same in both cases, or 9° 35′ 40″:

	Pounds.
Whole resistance	109.23
Friction on sides and bottom, 112.56 square feet	64.57
Plus and minus pressure	44.66

Referring to example No. 3, it will be seen that the plus and minus pressure for the body at the surface was 72.02 pounds.

The difference between 72.02 and 44.66 pounds shows less resistance for the body with the horizontal end wedges, = 27.36 pounds, which is not less than 21.1 per cent. of the whole resistance. And even including the friction, although the body with the horizontal end wedges has the largest immersed surface by 13.18 square feet, its resistance is yet 19.97 pounds less than that of the body with the vertical wedges.

No. 5.—*The body submerged* 6 *feet below the surface.* (*Speed*, 8 *knots.*)

(Beaufoy, p. 345.)

The middle part of the body was a parallelopipedon, 10 feet long, section one square foot, with a vertical wedge at the fore end; angle of obliquity, 9° 35′ 40″, and a horizontal wedge at the stern end; angle of obliquity, 19° 28′ 16″:

	Pounds.
Whole resistance	80.25
Friction on 57.614 square feet	33.15
Plus and minus pressure	47.30

(Beaufoy, p. 349.)

The body was exactly like the foregoing, except that the wedge astern was vertical with the angle of obliquity as before, 19° 28′ 16″:

	Pounds.
Whole resistance	85.65
Friction on 53.372 square feet	30.71
Plus and minus pressure	54.94

Showing a difference of resistance = 7.64 pounds in favor of the horizontal stern wedge, being equal to 9.5 per cent. of the whole resistance. Including the friction, the resistance to the body with the horizontal stern wedge, although its surface is the largest by 4.24 square feet, is yet 5.40 pounds less than to the body with the vertical stern wedge.

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